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ERRATA

Page 30, line 6 from foot. *for* "former" *read* "latter."
,, 214, ,, 4 ,, top. *for* "F_2O_3" *read* "Fe_2O_3."
,, 242, ,, 10 ,, foot, *for* "eight" *read* "ten."
,, 242, ,, 7 ,, foot, *after* "Kilpatrick;" *read* "Earlsburn; Ratho (pectolite pseudo after analcime);"
,, 253, ,, 4 ,, top, *for* "(210)" *read* "(310)," *and for* "(310)" *read* "(210)."
,, 253, ,, 4 ,, foot, *for* "(310)" *read* "(210)."
Plate XIV., Fig. 1, *for* "r" *read* "y," *and for* "y" *read* "r."

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1893-4.

ANNIVERSARY ADDRESS.

I.—*Western Australia and its Goldfields.* By ALBERT F. CALVERT, M.E., F.R.G.S. *Read at Anniversary Meeting, 16th November* 1893. (*With Map, Plate I.*).

IN presenting to your notice the following brief description of the Goldfields of Western Australia, I desire to convey to this Society my thanks for the honour you have done me in inviting me to be present before you this evening, and thus enabling me to deal with a subject in which I take such a deep interest, viz.:—the Goldfields of Western Australia. Little has been printed about this vast colony which I have not read; and I have likewise endeavoured in a humble way, within the last few years, to see for myself some evidences of her future greatness. Three times I have explored the North-Western district. On the first occasion I started from London early in April 1890, and made an expedition lasting three months. Again, in April 1891, I was engaged to make further investigations over the same line of country; and lastly, I visited the North-West in the present year. Then, from time to time, I have made a point of sailing to every port from Cambridge Gulf to King George's Sound, sometimes in regular coasting-vessels, and sometimes in small vessels which I hired for the purpose. From each of these ports I made journeys inland of varied duration, and with various objects in view.

Western Australia has at present three great obstacles to her progress. The first is physical—her lack of water, which can only be combated by science. The second, her scantiness of population, is being slowly removed. The third can readily be surmounted, if confidence in her great mineral resources is once inspired. I refer to her lack of capital.

As will be seen from the following particulars of the fields,

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every district is more or less hampered from the same cause. Mr Renou, the Superintendent of Water Supply, in his recent report on the water supply at Southern Cross and Coolgardie, draws attention to the disasters which drought may yet bring in its train. He points out that the district is the most arid in Australia. Natural watercourses, or permanent surface waters, there are none, not a single stream finding its way to the sea for many hundreds of miles on either side. The rainfall is not only slight but uncertain. If next summer turns out a dry one, a condition of things may result which may easily become appalling. The provision for water at Coolgardie is altogether insufficient, even for a usual summer, so Mr Renou tells us. Should the summer be a long one, the crowd of prospectors and miners may be actually caught like rats in a trap. Retreat, even for those at Coolgardie, will be difficult; but it will be impossible for them to stay. At this locality a couple of tanks have been made, of which the Superintendent of Water Supply says that one should hold 525,000 gallons, while another is a failure. In any case, he remarks, even should the tanks be filled, their supply cannot last through the ensuing summer. The attempt to sink wells has proved abortive, but the failure to make tanks is the more blameworthy because the ground seems to be excellently adapted for this purpose.

At Southern Cross, where Mr Rollo is at present engaged in boring operations, it is a question whether the labour which is being expended will be of much permanent use. Mr Renou recommends the utilisation of the lake at Southern Cross by excavations, for the supply of the principal mines, and he demonstrates convincingly that this can be done with comparative facility, and at moderate cost.

Science, however, has come to the aid of the miner and bushman in other quarters, and may be said to have vanquished this horror of the desert. Queensland and New South Wales have demonstrated that plenty of water may be obtained by artesian boring. Day by day fresh reports come in of the striking of water in one or other of the many bores now being drilled all over the dry belt of Western Queensland and New South Wales. An enormous area of that arid territory has been found to be water-bearing, and drought is fast losing its terrors for the farmer and squatter. As yet there is no indication of a diminution in the vast supply of under-ground water, owing to the number of vents which the hand of man has opened for its escape. Just as irrigation has proved the salvation of many a rancher on the prairies of Colorado, so has artesian water rescued from ruin many a pastoral property in Queensland and New South Wales.

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Let me turn for a moment to the geographical aspect of the Colony.

A perfectly straight line north and south divides Western Australia from the other colonies. It includes all that portion of the great Island Continent westward of 129 degrees east longitude. Its greatest length from north to south is 1480 miles, and its breadth from east to west 1000 miles. Two thousand miles of her sea-board is on the Indian Ocean, and 1000 miles of her coast is washed by the Southern Ocean. There are six land divisions—viz., South-west, Eastern, Eucla, Gascoyne, North-west, and Kimberley.

The South-western Division is at present the most important, and by far the most thickly populated. It naturally subdivides itself into three sections. On the east, the line of river watershed separates the more settled neighbourhood from the wild interior; then the great forest lands, extending about fifteen miles from the sea; and lastly, the coast districts on the south and west. The Great Southern Railway runs from Albany to Beverley through the first-named section; the finest timber grows on the second, which is likewise rich in stream tin, while coal and other minerals only wait development. The third again is unrivalled as an agricultural settlement.

The vast Eastern Division is only partially explored, but is in many parts richly grassed, and suitable for raising cattle and sheep. This section, moreover, includes the Yilgarn Goldfields, to which I shall refer more fully hereafter.

Of the Eucla Division only a portion has been explored. It contains some excellent pasture-lands, and when the water difficulty has been overcome by artesian wells and other scientific resources, it will doubtless prove an advantageous field for settlement.

The Gascoyne Division is watered by several rivers—viz., the Gascoyne, Minilya, Murchison, Greenough, and Lyons rivers. Horses, cattle, and sheep are successfully raised, and gold has been found in large quantities on the Murchison, Gascoyne, and Ashburton rivers.

The North-Western Division is watered by the De Grey, Shaw, Coongan, Fortescue, Sherlock, and other rivers having their sources in the granite ranges of the interior. This is a very important grazing district, and here are the extensive Pilbarra goldfields.

The Kimberley Division, to the north of the Colony, covers an area of 34,000 square miles. Here the climate is tropical, but it is rich in pasture-land, and its gold resources have been abundantly proved. Distance and difficulty of access have of course prevented its full development.

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According to the latest computations, the total area of Western Australia is 678,400,000 acres, or 1,060,000 square miles. This vast tract of country, nine times the size of England, Scotland, and Ireland combined, has just reached a population of 60,000 souls, entitling the Colony to an elected Upper House, in terms of "The Western Australian Constitution Act, 1890."

In dealing with the geological formation of Western Australia, it may be stated that the general character of the auriferous country in this Colony is a series of belts following in the south the coast line which is a little to the W. of N. and E. of S. The gold reefs traverse the lower Devonian schists which are more or less altered by the action of the dioritic bosses which have distorted them in many places. These schists lie directly upon the granite, which has lifted them to an angle of between 30 to 45 degrees. The granites do not appear in a mountainous form, but take the shape of low ranges which in many districts have not outcropped more than sufficient to give the country an undulating character. It is these north and south belts where the diorites and sometimes trachytes have played their part, which are of exceeding importance from an auriferous point of view.

As we leave these auriferous belts of Lower Devonian schists, we approach more level country, which may be characterised as Upper Devonian sandstones. These appear to be almost entirely devoid of animal and vegetable life, and there are vast tracts of these sandstones whose *fauna* might be reduced to the *spinifex* (*triodia irritans*). The annoyances caused by this plant *the spinifex* are not realised on this side of the globe; but the very name of this vile growth is enough to send thrill of horror through the Australian bushman. These sandstones occupy a large area, and here and there patches of clear plains have several inches of salt. In fact these sandstones are in many instances highly saline, and after sinking for water, it often turns out too brackish to be of any value for domestic purposes; whereas wells sunk in the schists near the granites yield a supply of pure and wholesome water.

These auriferous belts following the coast line, nearly north and south are deemed to be a system of parallels. Two of these have been already traced at intervals and proved to be very rich, but a third parallel may possibly exist further in the interior, though up to the present time its existence has not been fully demonstrated. Now these parallels extend northwards for about 1000 miles, when the coast suddenly alters its geographical contour and runs eastwards. The auriferous belt has accommodated itself to this change of circumstances, and

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departing from its original line swerves round and follows the line of the coast, taking a direction of a few degrees north of east. This is an illustration of how the geographical features correspond with the geological; or rather, how the geological conditions have evolved the present coast line.

The old "travellers' tales," whether true or false, seem to have been utterly ignored by the early settlers in this Colony, and it was not until 1840 that rich deposits of lead and copper were found in the Champion Bay district. Several very rich lodes between Geraldton and the Murchison, and adjacent to the coast, were worked by English companies, in a raised belt of country, extending from the Geraldton mine on the Murchison river in the north, almost to Geraldon in the south. The ores in these lodes usually consist of galena (sulphide of lead) and cerussite, associated with quartz, calcite, barytes, and blende (sulphide of zinc). The galena occurs massive and crystalline, and contains very little silver, any which is found being usually granular. Where cerussite (carbonate of lead) has been found, lead poisoning has been prevalent, having in some instances caused a stoppage of the works. Most of the old workings are now abandoned and full of water. There are some lodes, however, which have never been touched, and others that have been little worked. Although a railway was constructed thirty-four miles in length from Geraldon to Northampton, these mines have been practically deserted for about thirteen years, the chief reason being the fall in prices of copper and lead. It is believed, however, that the lead mining industry would prove remunerative if proper smelting works were established, and the Government offers a premium of £10,000 for the first 10,000 tons of metallic lead produced. A small local company was formed some time ago, but collapsed through want of capital, after producing several tons of pig lead, and thereby proving the practicability of the scheme if adequately managed and supported. According to the Government geologist, lead ore dressed up to 83 or 84 per cent. can be obtained in this district, whilst the coal seams on the Irwin river, about sixty miles distant, are quite suitable for smelting purposes, and there is an abundance of ironstone. Since 1845, when the first shipment was made, 7917 tons of copper and 31,105 tons of lead ore have been exported from this neighbourhood.

In 1846, the Messrs Gregory found coal seams in the bed of the north branch of the Irwin; and Dr Von Sommer, who reported thereon, soon afterwards stated that there were two seams of six and eight feet in thickness respectively. Two thousand five hundred and sixty acres were declared, but nothing was done for many years; and although the authorities

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sent the Rev. C. G. Nicolay to make investigations, his report was such as to discourage investment. This field, such as it is, has now passed into the hands of the Midland Railway Company, who intend to test its true value.

Other minerals in vast quantity are hidden beneath the soil of Western Australia. Of this we have abundant proof, although the tiny army of prospectors and miners who have tried to test her mineral wealth could make comparatively little investigation on a territory of 700,000,000 acres.

A few of the discoveries are as follows :—

Silver has been found associated with lead ores in the Northampton and Roebourne districts. Copper exists in large quantities in the Northampton district, and also at Mullewa, Murgoo, up the Murchison, near Roebourne; while at Whim Well there is an immense lode.

The Northampton district is rich in lead, which also occurs in smaller quantities near Roebourne. The Western Shaw and Pilbarra districts have produced tin. Iron is found throughout these districts, and one of the largest lodes in the world is in the Weld Range.

The Northampton district yields zinc.

Coal exists in many parts of the Colony.

The Gascoyne River and Northampton District show the presence of graphite in considerable quantity. Mica exists near the Shaw and on the Gascoyne.

At the Nullagine kaolin has been discovered.

These facts, I think, bear testimony to the incalculable store of mineral wealth which Western Australia's hundreds of millions of acres may be supposed to conceal from the eye of man.

Although the ancient charts and maps point to the existence of gold in Western Australia, modern geologists for a time denied that the metal was present in the colony.

Since the time when Sir Roderick Murchison proclaimed his disbelief in the existence of gold in the Colony, the great auriferous wealth of the western parallel has been abundantly proved. A belt of gold-bearing country extends from Phillip's River, in the south, up through the Yilgarn, Murchison, Gascoyne, and Ashburton Goldfields. Then there seems to be a parallel further to the east, extending from Dundas Hills in the south to Ularring and Kimberley Range, then passing the heads of the Murchison and Ashburton Rivers, and possibly reaching to Marble Bar and Nullagine, where the belt may possibly be intersected by another, which, running east and west, cuts it at right angles. This latter assumption is not put forward as an ascertained fact, but merely as a possible suggestion as to the general run of the Gold Reefs.

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It is impossible to exaggerate the magnificent outlook on these vast tracts of auriferous territory. With the progress of exploration and discovery, new resources of wealth are appearing, and immense openings are revealing themselves for the employment of capital and labour.

Many of the alluvial deposits have already yielded large returns without the use of machinery. These cannot, however, be reasonably expected to last. The future prosperity and permanence of the West Australian Goldfields lies in the working of her great Quartz Reefs. To efficiently do this demands enterprise on a large scale, backed by capital and scientific skill. Then will the element of chance be reduced to a minimum, and gold mining be conducted on a basis of systematic calculation, like any other technical branch of industry.

Distance, drought, and scarcity of timber, from which some districts suffer, are difficulties of nature, which, however, can be largely overcome by science; and the vast mineral wealth to be secured will amply justify the employment of best means known to man.

In 1882 the late Mr E. T. Hardman examined the Kimberley district, and it was his report on the same territory, three years later, which led to the establishment of the gold mining industry in Western Australia.

The "Cinderella of the South"—as the Colony has been called—was the last of the colonies to come to the front as a gold-producing territory. Each of her colonial sisters had already passed through the ordeal of gold fever.

In dealing with the several Goldfields of Western Australia in detail, I propose, in the first place, to describe the last proclaimed field of Dundas Hills, which are situated about 120 miles north from Esperance Bay. They are extremely rugged in appearance, and consist of bare rocks, timbered here and there in patches. On the side of the dry salt lake they have a cliff-like aspect, and many rocks stand out from the waterless lake bed, through which run several well-defined reefs. These are wide, and seem to run regularly, the tract leading into a gully, which extends half-a-mile into the hills. Colours of gold have been got in these reefs; but little prospecting has been done as yet. The auriferous country is probably a narrow strip running north and south, and showing on both east and west sides of the hills, which are mainly of ironstone, with occasional glimpses of quartz. Several gullies intersect the hills, but do not exhibit alluvial, nor do the reefs seem rich enough for dollying. In short, this ground, although very promising, is not the place for the poor man or amateur, at all events until the advent of machinery.

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The camping ground is at a soak in the gully, surrounded by hills. Here water was forthcoming during several months this summer, sufficient for thirty men and twenty-five horses; but by last reports it was nearly dry.

The Yilgarn Hills consists of a low range about 250 miles east of Perth, on the western side of a series of salt lakes, of which Lake Deborah is the southernmost. They run for the most part north and south, their width ranging from two to three miles. On the eastern side they extend, with gradual declivity, towards the lakes, being separated therefrom by a plain four to six miles wide, consisting of red clay, strewn with ironstone and quartz.

The rocks are mica schist, mica slate, and flaggy quartzites, with many diorites and quartz veins. They have been tilted up from the west by a large mass of intrusive granite, which forms a rough face on the western side of the northern hills, and is again seen in the southern part, appearing above the plain in huge rounded masses. The quartz reefs follow the strike of the rocks, and show great variety of character, the white quartz being less clearly defined and in smaller masses than the more ferruginous reefs.

"Yilgarn" is the native name for white quartz, and the first discovery of gold in this district was made by Mr H. E. Anstey, at the end of 1887, at a place called Emun, about twelve miles north of Golden Valley. The next discovery was made at Golden Cross itself, a few months later. Then about the middle of 1888 gold was found some forty miles south, near the Central Mine in the Southern Cross district—the latter place so called from its first discoverer having been led thither at night-time by the aid of the stars. In December 1888, Mr Parker, guided by a native, made a further discovery some forty miles to the south-east, hence the name of Parker's Range.

Generally speaking, the stone is rich, often containing six ounces of gold to the ton; and trial crushings have shown that a very large mass carries a remunerative proportion. Rich alluvial deposits have likewise been found, but scarcity of water has proved a serious obstacle to progress. Plenty of brackish water, however, is obtainable, which, by the use of condensers, is rendered available for steam purposes. The conservation of the rainfall by the use of catch-dams, however, may yet supply the wants of the mining population for domestic and drinking purposes.

Coolgardie is, I believe, within the proclaimed boundary of Yilgarn; but as it is 120 miles to the south-east of Southern Cross, it may be treated as a separate goldfield.

In October 1892, Mr Bayley, a miner who was prospecting in

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this neighbourhood, made one of the richest finds in the history of gold mining. The news of the discovery speedily sped to Perth, and in November of last year, Mr Sylvester Browne, who happened to be in the Colony, travelled to Coolgardie, and bought Bayley's Reward Claim from its original holder for £6000, and a one-sixth share in the mine.

Bayley's Reward Claim shows a reef, which consists of a small blow running in a north-westerly direction, and underlying to the north-eastward, striking across the line of country, which here runs nearly north and south. This reef is about nine feet broad in its widest part, but pinches towards either end of the claim. At the north end there is another blow of quartz, which strikes north and south, following the line of the strike of the country. This blow then dips under the alluvial flat, but a reef, on exactly the same line, is met with in a shaft in the gully, after which it appears to be lost. In one year Bayley's Reward Claim has yielded half a ton of gold, with no battery, and here I have a photograph showing 4205 ounces of this gold, valued at about £16,820.

In many parts of this colony specimens have been obtained on the back of the reefs giving half gold and half quartz; but at Coolgardie the record has just been beaten, as a sample of gold quartz, weighing 10 lbs., gave 9 lbs. of gold!

The Murchison Gold Fields are situated about 320 miles to the eastward of Geraldton, or about eight days' journey. The road for the first sixty miles is rather bad, the first thirty miles being chiefly sandy hills, where water is scarce; and the second thirty miles crosses a sandy desert quite destitute of water. The remaining distance, however, leads through the bush, and presents no great difficulty, water being obtainable at easy stages.

The territory begins to show auriferous signs within eighty miles of the diggings, and several belts are passed over which are well worth prospecting. The fields, as you approach, are full of such indications as gladden the eyes of a practical miner. Quartz and ironstone in fragments strew the entire surface, and outcrops of the same are visible in all directions.

The proclaimed area of the Goldfields is 32,000 square miles; the principal auriferous belt being situated at the eastern side of the district. It runs in a north and south direction, from West Mount Magnet to Austin's Lake, and then in a north-easterly direction to Lake Annean and Yagahong. Other rich patches exist farther east, and a few patches have also been discovered nearer the coast.

These fields were the result of a discovery by John Connelly, near Lake Annean, and his find is now being worked at the

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Nannine Mine. It may be mentioned that at Mulga Mulga and Yuin in this district, gold had previously been found, but not in paying quantity; hence the search was abandoned for the time.

The geological features are described by the Government geologist as "the ruined remains of a vast, high, sandy table-land, presenting to-day a broken surface, consisting of salt marshes or lakes fringed by salt, sand, clay, and gypsum flats, from which rise low rough hills of metamorphic rocks or white cliffs, on the top of which are sandy plains, the remains of the ancient tableland. There are no well-defined rivers, but the few creeks discharge themselves into the salt flats, where the water evaporates, except after excessively heavy rains, when they overflow into rivers which run towards the coast. The hills are mostly small and low, consisting of ridges of hard metamorphic rocks, near which the rich finds of gold have been made. These are often capped by the same horizontally bedded formation exposed in the cliffs at the edges of the broken table-lands, which are generally covered with dense thickets of low scrub." As has already been said, nature's most formidable obstacle in the path of the gold-seeker throughout the Colony, is want of water; but the Murchison district is fairly well provided with the necessary of life. Near the salt lakes there is a scarcity, but even there, if the well be sunk a short distance from the edge, the water is found to be fresh.

In most of the mines good water has been struck considerably under 100 feet down, and in fact it does not appear that scarcity is likely to hinder the development of these fields. The lack of timber is more to be dreaded as an opposing factor, particularly at the south end of the field, where there is nothing but mulgar.

The River Ashburton, which is about 500 miles in length, has its source in the Gascoyne Division of Western Australia, and flowing in a north-easterly direction, discharges its waters into the Exmouth Gulf, in the North-West Division. Early in 1890, alluvial gold was discovered in this district, on a creek running down a gorge about 200 feet deep, between steep cliffs of clay slate, capped by almost horizontally bedded limestones. The point at which the discovery was made, is about 150 miles from the coast, and the Ashburton goldfield was duly proclaimed in December 1890.

The auriferous belt of country comprised in the Ashburton Goldfields, extends from the junction of the Hardey River with the Ashburton, a little to the north-east of Mount Clement, following the latter river in a south-eastern direction for about 150 miles. It is bounded on the south by the Barlee Range, and a flat-topped table-land, which follows at a distance of about

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14 miles to the south, the main course of the river. To the north it extends across the Ashburton and Hardey Rivers to Mount Wall and Mount de Courcy, a distance in a northerly direction from the river of from about 20 to 30 miles, giving an auriferous area of some 1800 square miles greater than the proclaimed area—*i.e.*, about 10,000 square miles.

The rocks, for the most part, consist of clay and chloritic slates, sandstones, and quartzite (the slates occasionally showing good cleavage), and are intersected by numerous quartz and ferruginous lodes. I may remark that the rocks are very similar to those found in the auriferous areas of other Colonies, but differ from those in other countries.

In passing on to Pilbarra, it must be remembered that these fields suffer from the lack of opportunities enjoyed by the more fortunate southern fields. Coolgardie has been assisted by sensational discoveries; the Murchison has had the advantage of a certain reputation, and a more accessible situation; while Yilgarn has been supported by the favour of the Government. Moreover, all these fields are in the southern district, and are the first to catch the eye and ear of the speculator.

It is an extraordinary thing that with the exception of my own efforts to bring Pilbarra to the front, I am not aware of any other person outside the Colony who had attempted to describe or has even mentioned this important field. Even the Government Geologist, after devoting sixteen pages of printed foolscap to the Murchison fields in his report of 1893, dismisses this district in *one line*:—"Pilbarra and Ashburton," he says, "have neither proved yet to be large reefing districts, *so need not be mentioned.*" Pilbarra has truly suffered from every ill that a distant, untried, and unknown goldfield could be heir to, but it has always possessed a few miners having pluck and knowledge to test its capabilities. It is to the courage, faith, and perseverance of these men that Pilbarra owes its recognised existence to-day, and the same pillar of strength which unearthed and supported it in the past, seems certain to carry it onwards to success and prosperity in the future.

The Pilbarra Goldfield has a proclaimed area of 32,000 square miles, and is situated in the north-west district of the Colony.

Its general features are alluvial plain, which follows the coast-line, broken occasionally by rocky hills, and a high tableland to the south and east.

On the northern edge of this plateau several rivers have their sources, and cut deep gorges through the upper horizontally bedded rocks, which expose crystalline rocks across the line of their channels. These gorges run towards the north and north-

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west, first through limestone and quartzite rocks, then through flats bounded by rough sandstone and by deep ravines through broken hills of schists, slates, sandstones, quartzites, conglomerates, and amygdaloids, into alluvial plains, from which rise occasionally bold hills and small peaks of quartz, granite, and ironstone. These plains stretch to the sea-coast, where they are fringed by mangrove swamps, except where trap-rocks form a rugged coast. The amygdaloids in many places split into rough blocks, which become red or black on the surface, and then present the appearance of a huge heap of stones, without soil or vegetation. They contain vast numbers of agates, crystals, and other enclosures, so that the streams permeating them would be worth prospecting for precious stones.

There are many subordinate fields within this great area, which probably carries, sleeping within its veins, countless millions in the shape of virgin gold.

These fields, again, are divided and sub-divided as claims are taken up. I will endeavour to enumerate and describe the most prominent of these districts and properties.

The Marble Bar field lies in a nest of low sandstone and slate hills, to the east of the Coongan River, and is distant from Roebourne about 275 miles.

No field that I have visited, and no district of which I have studied the report, appears to me to hold out more brilliant prospects for the future.

Without that modicum of assistance accorded by the Government to other and far less deserving fields, the Marble Bar Reefs have abundantly proved their quality. Both this field and its neighbour, Bamboo Creek, were opened up by ideal pioneers among the gold finders, whose innate perseverance and indomitable courage led them to penetrate far into the wilderness, and encounter inevitable distresses in these distant wilds. To these men, whose chief capital was their strong arms and stout hearts, may be attributed the early success and development of these fields.

The Nullagine district is situated on a creek of the same name, which is a branch of the De Grey River. By road it is some 300 miles to the eastward of Roebourne, and about 120 from the coast.

Alluvial workings of three classes occur.

First, the alluvium of existing creeks.

Second, the alluvium of older creek beds, but in conjunction with present streams.

Third, old alluvium deposits, or deep leads, bearing no relation to existing streams or configuration of the country.

All three deposits are very rich, and the more recent deposits very easily worked.

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There is probably a grand future in store for this neighbourhood.

One of the most extraordinary outcrops in the Pilbarra district, is an association of gold and antimony, called the Mallina Mine. Nine shafts have been put down in various parts of this reef, showing an increase in richness at the lower depths. I think a good deal of importance attaches to this reef, as without doubt here is a mine that will hold down to immense depths, and is probably the richest in the district.

I come now to the last of the great proclaimed areas of Western Australia under the "Goldfields Act, 1886"—viz., the Kimberley Goldfields. Although I place it last in sequence, owing to its geographical position, I might well have adopted a chronological method and placed it first.

The Kimberley Goldfield is situated in the north-eastern corner of Western Australia, and its principal workings are near the eastern boundary of the Colony, about 200 miles from Wyndham on Cambridge Gulf, and 300 miles from Derby on King's Sound.

So far back as 1882 the late Mr Edward J. Hardman, F.R.G.S.I., Government Geologist, had actually discovered the existence of gold in the Kimberley district. The subject may be said to have slept for three years, when it was revived, and gold prospecting began in earnest.

This country is traversed by the Margaret, Mary, Elvire, Panton, and Ord rivers, and comprises an area of at least 2000 square miles so far as observed, but it doubtless continues over a much greater extent of country. The formation is principally Silurian schists and slates, traversed by an enormous number of quartz reefs. In some localities many of these occur in the space of a few hundred yards, and it is quite usual to notice twenty-five or thirty large reefs while riding over a mile of ground, without taking into account the smaller reefs or veins. The quartz constituting these reefs is of a very promising character. It is a dull yellowish and grey quartz very cellular and vuggy, containing quantities of black and other oxides of iron, together with casts of, and often crystals of iron pyrites. From most of the surface quartz the enclosed minerals have been washed away however, although their traces are still apparent.

The quartz reefs have a general bearing of N.-E. Some run due N. and S. A few of them can be traced for several miles.

It is most probable that these quartziferous rocks are a spur or continuation of the gold-bearing metamorphic rocks of the Northern territory of South Australia, now being worked with success.

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A comparison between the progress of the Western Australian Goldfields and the early results from the South African Goldfields, reveals that whilst seventeen years elapsed before the South African Fields produced £200,000 of gold, the Fields of Western Australia exceeded that sum in the seventh year. It also shows that the out-put for the first seven years of the West Australian Fields has been more than double the African out-put for the first seven years. Moreover, Western Australia has exceeded by nearly £70,000 the out-put for the first fourteen years from South Africa. These results have been attained, notwithstanding the fact that hardly any of the mines in Western Australia have (owing to lack of capital) as yet been efficiently worked, and that a very small portion of the gold-bearing area has as yet been prospected.

I must claim your indulgence for the length of my paper, which perhaps has extended beyond the ordinarily allotted time; but I may say that it is difficult to deal shortly with a country containing nearly 700,000,000 acres; but which, in spite of all natural and other disadvantages, gives abundant promise of being in the near future the richest mineral territory in the world.

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Trans. Geol. Soc. Edinr. 1894. Vol. VII. Pl. 1.

J. G. Bartholomew.

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II.—*The New Geological Map of the Edinburgh District.** By HENRY M. CADELL of Grange, B.Sc., F.R.S.E.

(Read 18th January 1894.)

THE publication in 1892 of the Second Edition of the Geological Survey Map of the Edinburgh District illustrates the progressive nature of geological science, and the continual advances that are being made in our knowledge of the rocks beneath us. When the first edition of sheet 32 was published in 1859, the Geological Survey of Scotland was in its infancy, and during the thirty-three years that have elapsed great additions have been made to our knowledge, both of the geological structure of the district and of the petrographical characters of many of the rocks included within its boundaries.

As a large part of the western division of the map between the Pentland axis and the Firth of Forth is deeply covered with drift, and the natural sections are not extensive enough to reveal the true nature of the complex stratigraphy of the district, it was in 1859 impossible to indicate with any certainty the correct structure of a great part of that area. Since then the discovery of productve oil shale and the rapid development of the paraffin oil industry has led to the opening up, by pits, mines, and mineral workings, of many districts whose structure would otherwise have still remained wrapped in their ancient darkness, impenetrable even to the searching eye of the geologist. Notwithstanding the thousands of borings and mineral workings, however, there is still a considerable tract of country west of the Pentland axis remaining to be deciphered, and this will fall to be done by some future geologist bent on handing on the lamp of truth and showing to a future generation that in geology, as in other branches of human knowledge, the goal of finality can never be perfectly attained to.

Beginning with the oldest rocks, which appear along the ridge of the Pentlands, we note several important changes on the map. These are due not to any newly exposed sections, but to improvements in the mapping and petrographical nomenclature

* The original map was surveyed geologically by Mr Arch. Geikie, who worked on the Western area, and by Mr H. H. Howell, who mapped the Dalkeith Coalfield, and was published in 1859, Sir Roderick Murchison being Director-General and Mr A. C. Ramsay Local Director. The second edition was published in July 1892, after revision by Sir A. Geikie, F.R.S., H. H. Howell, B. N. Peach, F.R.S., J. S. G. Wilson, and H. M. Cadell, Sir A. Geikie being Director-General and Mr H. H. Howell Local Director.

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of the massive rocks of the range. The rocks denoted as Felstones on the old map, and composing the greater part of the north-eastern end of the Pentlands, are now denoted Porphyrites and Andesites, while several of the more ashy spots are now recognised as volcanic necks—the plugged up pipes of old volcanos piercing the bedded lavas. Interbedded with the basic porphyrite lavas are a series of mere acid rocks consisting of rhyolites, trachytes, liparites and ashy beds, well exposed along the crests of Carnethy and Scald Law. At the base of these volcanic beds there is a great mass of conglomerates and sandstones now recognised as the base of the middle division of the Old Red Sandstone, resting in violent unconformability on the upturned edges of the Upper Silurian and Lower Old Red Sandstone core of the range. In Monksburn these basal conglomerates have a local thickness of nearly 2000 feet, and many of the overlying acid lavas have recently been found to show beautiful perlitic structure and well marked rhyolitic banding along their outcrops. The most conspicuous of the "necks" shown on the new map are those of the Braid Hills and Torduff reservoir, while the Black Hill, overlooking Threipmuir reservoir, is now shown as an intrusive mass of Felsite of pre-carboniferous age, piercing the Ludlow-Wenlock shales and cut off from the inter-bedded rhyolites on the south by a powerful fault.

The Lower and Middle Old Red rocks, with their volcanic series, are covered unconformably by the Upper Old Red Sandstone, which graduates upwards conformably into the base of the Carboniferous system. At some places, however, the Lower Carboniferous strata overlap the Upper Old Red sedimentary beds, and in the neighbourhood of Warklaw Hill rest directly on the volcanic series. As the basement beds of the Carboniferous system are also red and conglomeratic at places, it has often been a matter of opinion where the dividing line should be drawn, in absence of clear palæontological evidence on the point. The new map differs markedly from the earlier one in this respect, as it will be seen that a wide area of moorland at the S.W. end of the Pentland ridge which was formerly included in the Calciferous Sandstone series, is now relegated to the Upper Old Red, and at the north end of the range the red rocks at Liberton and in the district north and west of Morningside are included in the same formation.

With these modifications the general outline of the Carboniferous system remains comparatively unaltered, and the changes now to be noted are confined chiefly to the details of the individual beds, faults, and eruptive rocks in the Carboniferous area.

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The Calciferous Sandstone series, situated between the Upper Old Red and the Mountain Limestone, includes in its upper part the economically important Oil Shale series. Before passing on to this, however, we may note that a great improvement has been made in the part of the map north of the Forth, which now includes in the Calciferous series a considerable part of Fife which was formerly regarded as of Carboniferous Limestone age. It was very difficult to understand the structure as explained by this part of the old map, since the strike of the rocks along the south shore westwards from Queensferry is, roughly speaking, north and south, and the boundary line of the Calciferous series could not well be drawn east and west down the centre of the Firth at right angles to the strike, without presupposing a very large fault of whose existence there is no clear evidence otherwise. It is, however, now made plain that the Calciferous series extends across into Fife, along a flat anticline, the continuation of that which is well exposed on the south shore below Hopetoun House.

The most important additions to the map are to be found in the triangular area between the Firth of Forth and Cobbinshaw reservoir, at the south-west corner of the sheet, within which the more important fields of oil shale are situated. A glance at the West Calder district shows how complicated the structure is in some localities. The rocks are not only very variable in thickness, but are bent about into multitudes of irregular folds, basins, and domes. These are in turn cut up in all directions by faults of varying dimensions, some of which run for miles across the country and extend westwards into the adjoining sheet, where their continuations may be followed into the coal-fields of Lanark and Linlithgowshire. It is a curious fact that immediately after we pass westwards beyond the boundary of sheet 32, into the Carboniferous Limestone series in sheet 31, we go out of this excessively "troubled" area, and for many miles the strata are found striking north and south and dipping steadily westwards with few important local variations, the only breaks in their outcrop being at those places where the strike of the beds is interrupted by the more powerful of the faults just referred to.

In the West Calder district the whole succession from the Burdiehouse or Camps estuarine Limestone may be traced upwards to the Hurlet or Mountain Limestone, and it is within this zone that the majority of the workable oil shales have hitherto been found. A list of the seams of shale is given on the map, and several descriptions of the section of the oil shale group of the Calciferous Sandstone series have been published within the last few years from information derived from mining sections.

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In the Broxburn and West Calder district the general section of the series, as published in a paper by me in the *Journal of the Iron and Steel Institute* for 1888, is as follows:—

	Ft.
Strata below the Hurlet Limestone, about . .	400
Raeburn's Shale 3 to 4 feet.	
Strata	190
Mungal's Shale about 1 ft. 9 in.	
Strata	170
Coal and Grey Shale 2 feet.	
Strata, Houston Marl Group	200
Houston Coal and Shale 3 to 12 feet.	
Strata, usually laminated sandstones . . .	240
Fells Shale 3 to 5 feet.	
Strata, Broxburn Marl Group	80 to 270
Broxburn Shale 2½ to 8 feet.	
Strata, including the Binny Sandstones . . .	450
Dunnet Shale 6 to 13 feet.	
Strata, thickness imperfectly known, say . . .	400
Barracks Shale, resting at places on the Burdiehouse, Camps, or Queensferry Limestone, thickness very variable.	
Strata about	780
Pumpherston Shales.	
Apparent approximate thickness of oil shale group	3100

These figures are only rough approximations, as the local variations in the thickness of the strata between the recognisable horizons are so great that it is impossible to draw up any general section applicable to an extensive area. At some places the shales which are elsewhere of economic value disappear as oil producers, and at others it is often a matter of great difficulty, in the absence of well-marked horizons, to identify the positions of some of the seams that are being mined. The Pumpherston Shales are, for example, apparently situated below the Burdiehouse Limestone, and are found cropping up round the crest of a very sharp steep anticlinal dome, on the west side of which a bed resembling the limestone has been traced in boring. In mining circles the position of this shale has given rise to much discussion, as the evidence for its geological position is by no means so clear as could be desired. The limestone outcrop shown on the map indicates a deep basin immediately to the west of Pumpherston Farm, the centre of which is occupied on the surface by a sheet of intrusive basalt, which at places cuts completely across the strata. The north end of the Pumpher-

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ston shale outcrop approaches very near an outcrop of the Broxburn shale—a horizon situated, according to the section, upwards of 1600 feet higher up in the series, so that, in the short space of half a mile, we have to explain a juxtaposition of two widely separated seams. There is no clear evidence of an ordinary fault, and as the dip is not sufficient to dispose of all this thickness of strata, it seems that here there must either be a local unconformability, or what is more likely, a thrust plane such as are found in the classic thrust region of the north-west Highlands, and have been ascertained to exist in nearly all the areas of great geological disturbances that have been carefully investigated within recent years.

The seams of the Mid-Calder basin again, which are superficially isolated from any well-known beds, are now known to lie above the Camps Limestone, and may thus be approximately correlated with the shales of the Broxburn series.

At Broxburn the Camps Limestone does not appear at the surface, the outcrop of limestone shown on the old map having now been proved to be nothing but thin calcareous beds in the Broxburn Marl group, with which the true Burdiehouse Limestone has no connection whatever. The thin blue line on this part of the old map therefore disappears in the new edition, and it is thus clear that over a considerable area two perfectly distinct horizons have been originally confounded, to the complete mystification of the geological structure of the district.

Passing northwards through a complex mass of small basins and faults, we come to another of the great east and west faults, a small part of which was recognised when the original survey was made. This dislocation has now been traced for a distance of about nine miles from the shore at Dalmeny, past Craigton, and thence westwards to near the complicated mass of igneous intrusions below Binny Craig, where it seems to run out and disappear along the strike of the beds. The Craigton fault has a branch running north-westwards through Hopetoun wood towards Blackness, the course of both faults being clearly traceable from the position of the limestone and shales which they truncate at various places between Hopetoun and Queensferry. Few changes have been made in the part of the map embracing the coalfield at Bridgeness, the geology of which has been tolerably accurately known for many years.

One notable change is, however, to be seen in the mapping of many of the volcanic rocks. The isolated patches of ash shown on the old map are now nearly all known to be necks piercing the calciferous strata, and are mapped accordingly. The more conspicuous ash necks are those at Carriden, Binns Hill, Niddry, Ecclesmachan, and the vicinity of Parkly Craigs and the canal aqueduct at Linlithgow.

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Two considerable changes are noticeable in the mapping of the eruptive sheets in the oil shale area. The first of these is in the district east of Murieston, on the Murieston and Linhouse Waters. On the old map the ridge of eruptive rock extending for about three miles eastwards from the Murieston limeworks, and forming the high ground of Corston Hill, is regarded as interbedded Felstone. This is now mapped as one of the older interbedded basalt rocks, situated a short distance below the Burdiehouse Limestone, and coming up along the shoulders of an anticlinal dome, which is cut off on the north-west by one of the large north-east faults. If this reading of the sections is correct, the trap must represent the top of an ancient ridge, against the steep west side of which the overlying strata have been deposited. There is no evidence of its existence immediately below the limestone on the west side of the fault. The latter rock here crops out at several places at high angles, and is apparently resting on a thick sedimentary series of beds, under which the trap must therefore within a very short distance, have become deeply buried. Further exposures may, however, clear up this somewhat doubtful point at some future date.

The other notable change is in the district west of the Pumpherston shale outcrop. The small patches of intrusive basalt shown on the old map have now been proved by numerous borings to be all parts of a thick sheet of trap extending continuously over several square miles between Uphall Station and Howden, and cutting at places completely across the strata.

Very little alteration has been made in the mapping of the Dalkeith coalfield, the boundaries of which are tolerably well defined. The chief change is in the separation of the limestones on the east into zones, and the addition of the oil shales at Straiton and Burdiehouse on the west. The shale series, which crops out in that limited belt east of the Pentland axis, is, as a whole, much thinner than the corresponding group on the west; but still there appears to be a general similarity in the succession, showing that the conditions favourable to the deposition of oil shale extended continuously over the site of what is now the Pentland ridge, thus leading us to the conclusion that new fields of oil shale may still be found throughout a considerable part of the district now included within this classic geological area.

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III.—*Kent's Cavern and Sir Henry H. Howorth's "Flood" Theory.* By RALPH RICHARDSON, F.R.S.E.

(Read 18th January 1894.)

Two remarkable works on Geology have recently appeared from the pen of Sir Henry Hoyle Howorth, M.P. for South Salford. The title of the first is "The Mammoth and the Flood: An Attempt to confront the Theory of Uniformity with the Facts of Recent Geology." This was published in one volume at London in 1887. The second work is entitled "The Glacial Nightmare and the Flood: A Second Appeal to Common Sense from the Extravagance of some Recent Geology." This was published in two volumes at London in 1893.

We at once observe from these two titles, *firstly*, that Sir Henry has serious fault to find with the teaching of "Some Recent Geology"; and *secondly*, that he brings on to the Geological stage a very old performer there—viz., "The Flood," which is apparently the veritable old Noachian deluge with which we are all so familiar in sacred and profane literature.

I think I may with perfect fairness give as the gist of Sir Henry Howorth's investigations as set forth in the works just named, that he considers that modern glacialists, from Agassiz downwards, have been entirely wrong in supposing that the action of ice-sheets has produced what they term the "glacial phenomena" of the earth's surface. Sir Henry Howorth holds that these phenomena were produced not by the action of the Ice-sheets but of a great Flood.

I do not, however, propose to meet his arguments in the glacial field. I leave that to far abler pens. I wish shortly to refer to his "Flood" theory as accounting for the accumulation of organic remains in ossiferous caves, such as Kent's Cavern, and to show why I cannot assent to that theory.

In the spring of 1886 I paid a visit to Kent's Cavern, near Torquay, and examined its contents both in the cave and in Torquay Museum. I also placed myself in communication with its famous explorer, William Pengelly, and received from him a copy of the address on Kent's Cavern which he delivered before the Royal Cornwall Polytechnic Society in 1886. In November of that year I read a paper before this Society, being the Inaugural Address of Session 1886-87, on the "Antiquity of Man and the Discovery of Fossil Mammalia in Devonshire

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and Scotland."[1] In the course of that address I minutely described Kent's Cavern, my description being, of course, based on Pengelly's lifelong researches.

Now, in what order do the deposits in this extraordinary cave occur? The very lowest deposit reached by Pengelly is a *breccia*, of unknown depth, containing remains of Bear, Lion, and Fox, besides rude, massive flint tools, establishing the presence of Man.

Above this breccia is a deposit of *crystalline stalagmite*, sometimes 12 feet in thickness. I beg your particular attention to this stalagmite, and another deposit of it to be mentioned presently, and I ask you to listen to Pengelly's description of its formation in his own words :—

"The roof of the Cavern is of limestone, and through it, in rainy weather, water percolates, slowly in most cases, but sometimes more rapidly. That water contains carbonic acid—the gas which is given off in an effervescing draught, and also by a burning limekiln. It is by that carbonic acid that the water dissolves the limestone which constitutes the roof. It reaches the inner surface of the roof, and hangs there as a drop. You go into the Cavern and hear a drop here and a drop there, and you know what process is going on. The limestone has been dissolved overhead, and as the water falls it brings a particle of Carbonate of Lime to the floor, where it is precipitated by the water. It sooner or later forms a little boss—more or less conical generally. Thence it flows away, and meeting that flowing from other such bosses, a sheet is ultimately formed which covers the entire floor. This is *Stalagmite*. A part of the carbonate of lime or limestone dissolved by the water remains on the roof, and by increase hangs down as a pendant. That pendant is *Stalactite*. The difference is not one of composition, but one of place only—the Stalagmite forming the floor, and the Stalactite depending from the roof. The stalagmitic sheet or floor cannot be formed more rapidly than the limestone is dissolved, which again is, to use a mathematical term, a function of the amount of carbonic acid in the water. Indeed, it cannot be formed *so* rapidly as the limestone is dissolved overhead; for, as I have said, a portion is retained on the ceiling. It follows, as a matter of course, that the formation of stalagmite is usually a very slow process indeed."[2]

Above the crystalline stalagmite of Kent's Cavern comes a deposit of light red clay loam, which Pengelly terms *Cave earth*, and which abounds with remains of the cave lion, lynx, wild

[1] Trans. Edin. Geol. Soc., Vol V., p. 337.

[2] Fifty-fourth Annual Report (1886) of Royal Cornwall Polytechnic Society, p. 52.

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cat, cave hyæna, wolf, fox, Arctic fox, glutton, badger, cave bear, grizzly bear, brown bear, mammoth, woolly rhinoceros, horse, wild bull, bison, Irish deer, reindeer, hare, beaver, voles, and *machairodus latidens*. Flints, implements, flakes, stone hammers, harpoons, &c., were the remains of man in this cave earth, which was usually of unknown depth, but certainly exceeded 4 feet.

The deposit, however, which overlaid the cave earth was the most abundant in its evidences of Man. Pengelly calls it a *Black band*, composed mainly of small fragments of charred wood, and commonly about 4 inches thick. It was, without doubt, says Pengelly, the "hearth of the old Cave-men." 366 flint implements, flakes and chips, a bone awl, needle, and harpoon, burnt bones and burnt wood, were found in this deposit.

Above this Black band comes a second deposit of Stalagmite, varying from a mere film to 5 feet in thickness. To distinguish it from the previous or Crystalline Stalagmite, Pengelly calls it *Granular Stalagmite*.

Above it is a dark-coloured mould, of from 3 to 12 inches thick, consisting largely of vegetable matter, which Pengelly calls the *Black mould*, and which forms the uppermost deposit of Kent's Cavern.

Let me recapitulate these deposits in descending order—*i.e.*, from top to bottom:—

Deposits.	Thickness.
Black mould, . . .	3 to 12 inches.
Granular stalagmite, .	Film to 5 feet.
Black band, . . .	4 inches.
Cave earth, . . .	Exceeded 4 feet.
Crystalline stalagmite, .	Sometimes 12 feet.
Breccia, ...	Unknown.

In all, deposits exceeding in depth 23 feet have been ascertained and classified.

Among these deposits are the two Stalagmites—one sometimes 12 feet thick, and the other sometimes 5 feet thick, deposits which occurred at a long interval apart from each other, and which (from the very nature of their formation, as already explained) must each have taken an enormously long time to be produced. Competent authorities have stated that it would take 1000 years to produce 1 inch deep of Stalagmite. Pengelly goes much beyond this. But even taking the calculation at 1000 years per inch, we find that the Crystalline stalagmite here would take 144,000 years to form; whilst, long afterwards, the granular stalagmite would take 60,000 years to form.

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Thus two vast epochs of the world's history would be occupied in producing these two deposits of Stalagmite alone; whilst, in addition to these two immense periods, a very great time is necessary to account for the successive deposits of the Breccia, the Cave earth, the Black band, and the Black mould.

It is somewhat startling to be informed, after this evidence of prolonged deposition, extending over several epochs, that the deposits in Kent's Cavern were due to such a temporary, transitory, and altogether inapplicable agent as a great Flood! But such is the conclusion at which I understand Sir Henry H. Howorth has arrived.

Sir Henry's work, "The Mammoth and the Flood," was published in 1887, or the year following Pengelly's Address on Kent's Cavern from which I quoted. But Pengelly began working at the Cave in 1846, and has been writing on it ever since. His Report to the British Association was finally completed in June 1880, after the continuous labour of fifteen years and three months had been spent on it. Pengelly says he went to Kent's Cavern every day of his life from 28th March 1865 to 19th June 1880.

Singularly enough, I can find no reference to the work at Kent's Cavern done by this veteran and illustrious explorer in Sir Henry Howorth's volumes on "The Mammoth and the Flood," and "The Glacial Nightmare." In the latter Sir Henry refers to Pengelly as "a very acute geologist, void of prejudices"; but it is to Pengelly's opinion on Boulders that he is there alluding.

Sir Henry, however, cites the Rev. John MacEnery, a Roman Catholic priest, resident at Torquay in 1825, who commenced in that year a series of researches in Kent's Cavern, and whose MS. description of the Cavern was in 1869 (he died in 1841) edited by Pengelly, and published in the Transactions of the Devonshire Association (III. 196-482).

This is what Sir Henry Howorth says about Kent's Hole or Cavern in his "Mammoth and the Flood" (p. 203):—"At Kent's Hole, MacEnery describes the bones as being 'intermixed with sand and gravel and marl, angular and rounded fragments, the former generally limestone, flat masses of which had fallen into the heap from the roof, where its under surface was coated with stalactite, cones and slabs of the latter scattered through schists and slates, and grauwacke, angular and sharp. The rounded substances consisted of small pebbles of limestone schist and quartz, green and sand stones.' Again, we read in the official reports of the exploration of the same cavern, that 'rolled stones, not derivable from the cavern hill, occurred here and there in every part which has been explored. They

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comprised pieces of granite from Dartmoor, crystalline schist from the Start and Bolt (15 miles off), and even of slate from the more immediate neighbourhood.' These stones (concludes Sir Henry) could only have been introduced by water."

"Whither, then," he continues, a little further on (p. 209), "are we to turn for an adequate cause for the results which we have to explain? If it was water, as seems inevitable, and if it was not water in the shape of a river, or of intermittent land-floods, there seems to be no other cause available than the great Flood which we were obliged to postulate as our only resource in the previous chapter. It is clear that such a flood would be exactly competent to produce all the results we find in the caves, and to meet all the difficulties of the case."

By describing Kent's Cavern as full of a rather jumbled up deposit, according to MacEnery's early narrative (as I have said, he died in 1841), and by not taking his description from Pengelly's recent and carefully systematised account, Sir Henry Howorth has, of course, missed the point of Pengelly's researches. If he had read Pengelly, he would have seen that there is in Kent's Cavern not merely one deposit, but six successive different deposits, laid down at six different times, at vast intervals of years.

Consequently we should require not one Flood, but six different Floods to lay down these six different deposits. This argument at once disposes of the contents of Kent's Cavern being due to a "great Flood" as suggested by Sir Henry. Besides, it has been clearly shown that the two deposits of Stalagmite are due, not to the action of a transitory Flood, but to that of calcareous drip going on for an extremely lengthened period.

As to the precise manner in which these deposits *were* laid down, that is purely matter of speculation. That water was an agent is very probable with regard to some of the deposits, but with regard to the two deposits of Stalagmite, one 12 feet and the other 5 feet thick, these deposits are, as I have said, not due to running water but to the calcareous drip from the ceiling of the Cave. When I visited Kent's Cavern I observed (as I stated in my paper) that "there are evidences, in the rounded form of parts of the interior that the Cave had once been swept by currents of water," but this remark, of course, applies only to the uppermost deposits and to the recent history of the Cave.

The sixteenth and concluding Report of the Committee appointed by the British Association to explore Kent's Cavern, was published in the British Association Report of 1880 (p. 62). The Committee consisted of Sir John Evans, Sir

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John Lubbock, and others, with Wm. Pengelly, F.R.S., as Reporter. I observed in this and the two previous Reports that the Committee carefully confine themselves to a description of what they *found* in the Cavern, and avoid speculation as to its origin or the mode of deposition of the Cavern beds. This is evidently a problem of great obscurity and difficulty; and if I have shown that its solution by a "great Flood," as Sir Henry Howorth suggests, is out of the question, the purpose of this paper will have been served.

Note.—Since the above paper was read, the following interesting account of a Cavern at Mentone, similar in some respects to Kent's Cavern, appeared in the *Scotsman* of 20th February 1894:—

THE CAVES AT MENTONE.

Much has been written about the Mentone caves, and yet their interest is by no means exhausted. Two years ago the scientific world was startled by the announcement of the discovery of three pre-historic skeletons in the Barma Grande, the deepest of several caves in the Baoussé Roussé—or red rocks—which form the eastern, or Italian, side of the Bay of Mentone. The skeletons were lying side by side, at a depth of 24 feet beneath the original soil of the cave. All were above ordinary stature, and one was gigantic, measuring as nearly as can be estimated seven feet. The skulls were of the dolichocephalic or long-headed type, and were remarkable for their large facial angle, good frontal development, and square orbits.

Three weeks ago, in removing soil from the cave for his garden, the owner of the quarry came upon another human skeleton. This time precautions were taken, and several scientific persons, among whom were Mr Arthur Evans and Mr Drury Fortarum, V.P. of the Society of Antiquaries, London, were present while it was being unearthed. This was done with great care, and occupied many hours. The present find lies 13 feet further in the cave than the former skeleton, and at a level of 6 feet above them—that is to say, 19 feet below the original floor of the cave. Ten inches of soil had been removed, consisting of burnt earth and the remains of charcoal hearth, which I had seen some weeks before. Above the middle of the body lay a large stone 28 inches by 27, 7 inches thick, rounded above and flat below, which suggested the idea of a small dolmen. This, however, it was not. One cannot be certain whether the stone had been placed there at the time of the

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burial or had fallen off the side of the cavern. Between the stone and the skeleton was about 6 inches of earth, in which were many bones of birds and the jaws of rodents (*arvicola*) of several species, and the stump of a deer's horn (*C. elephas*) with a piece of the skull attached.

The skeleton lies along the eastern side of the cave, with its head towards the opening; those of two years ago lay across the cave, with their heads to the eastern wall. It lies, like them, on its left side, in a somewhat curved position, the right leg crosses over the other at the tibia, the right arm is extended outwards, the left is bent up towards the head. The skull, which had been broken by the pick, is of the same type as the others, with broad, high forehead, strong jaws, and pronounced supra-orbital ridges and square orbits. The face is broad, measuring 5½ inches between the upper external angles of the orbits. All the teeth, including the wisdom teeth, are present in sound condition, but with the crowns much worn down. So we infer the individual to have been a man past middle age. Near the back of the skull a small flint knife was found, 4 inches long, and a minute carved bone ornament like a button. Round the head lies a row of shells of Cypræa, 1½ inches long, decayed so as to be unrecognisable. Beside them are a number of the canine teeth of deer, pierced through the sides. On the middle of the forehead, and adhering to the skull, are a number of small shells of Nassa Neritæ, pierced in similar fashion. The shells and teeth evidently formed necklaces or chaplets. It is interesting to find these canine teeth of the deer employed for decorative purposes. The North American Indian of to-day, whenever he kills a wapite, immediately draws the four canine teeth, and treasures them as charms. The pre-historic cave-dwellers seem to have had similar ideas. Only a small particle of ochre was found about the skeleton. This substance was spread in great abundance under and around the skeletons formerly discovered. Indeed, they seemed to have been laid in a kind of hollow, lined with this substance, which has quite discoloured the bones. It is thought that the ochre was buried along with the corpse, that in the other world the owner might have material wherewith to paint his body, as the Kafirs do at the present day. In the middle of the breast, below the chin and at the extremity of the left hand, lay a large natural crystal, 3½ inches long, of carbonate of lime, such as are common in the rocks around. From its position, it is inferred that it served some superstitious or religious purpose. From the presence of these things, as well as from the flint implement buried with the dead, we get faint glimpses of the religious notions of these ancient cave-dwellers.

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Like all the other skeletons that have been found in this cave, this one is of large proportions. The individual probably stood 6 feet 2 inches, though it is difficult to estimate the height exactly. The femur is 18 inches long; that of the giant found here two years ago is 20½. I managed with some difficulty, and with the aid of magnesium light, to take a photograph of the figure as it lay. The breadth of the face is well brought out in it.

For some weeks the workmen have been digging down to find the rock-floor of the cave at its mouth, and have run a mine into the soil. They are now working at a depth of 22 feet below the level of the skeletons—that is to say, 40 feet beneath the surface of the soil before excavations were commenced, and yet the rock has not been reached. The earth is full of the bones and teeth of animals. Already there have appeared those of the woolly rhinoceros, cave hyena, fossil horse, and the tusk and huge vertebræ and pelvis of an elephant or mammoth. Of the last, 2½ feet are visible, and the acetabelum, or socket for the head of the thigh, measures 9½ inches in diameter. Both above and for 18 inches below this bone are lines of charcoal, evidence of the early hearths of human beings who in all probability feasted on this elephant. The bone shows indication of having been partly burned in roasting. Lying beside the vertebræ of the elephant was a fine flint implement, 4¾ inches long by 2½ wide, with a sharp-cutting edge, and with one of its sloping sides flatter than the other, as if to be held in the hand between the fingers and the ball of the thumb. Mr Evans said it resembled the type of instrument now or but recently employed by the Maoris of New Zealand for cutting notches in the stem of a tree they wished to ascend.

In the cave no metal has been found, nor any vestige of pottery, nor is there any weapon of polished stone. Though the ornaments around the skeletons and the bones near them seem to point to a Neolithic race, the tools are all of the chipped order and indicate an earlier age, one for which Professor Issel of Genoa has invented the name of Miolithic. But who were the men that ate the elephant, and who have left the traces of their fireplaces so well marked in the deep soil, and of what race was the man that used the flint tool found beside the elephant's vertebræ? Assuredly Paleolithic. The whole soil of the cave is full of bones, entire or split for the extraction of the marrow. In the upper strata they are mostly of species used for food, *Bos primigenius*, *cervus* of three species, *ibex*, boar, &c. Lower down they are mixed, herbivorous and carnivorous. Throughout the soil fragments of flint are very numerous,

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though perfectly-formed tools are not plentiful. In the lower strata the chips are larger and coarser than those of the upper beds. So numerous are the flakes and cores that the cave would seem to have been used for a long series of generations as a manufactory of such implements. The material was probably derived from beds which are found not far off on the hills above, near which ochre is also found. The flint occurs in two kinds of places—sometimes embedded in the hard conglomerate, a thick stratum of which runs parallel with the coast; sometimes lying loose in a sandy, calcareous soil, in which it appears to have been segregated.

J. E. SOMERVILLE.

MENTONE, *February 16th*, 1894.

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IV.—*Notes on a Visit to the Copper Mines of Little Namaqualand.* By JAMES CURRIE, Jun., M.A.

(Read, 15th February 1894.)

IN the extreme north-west of the Cape Colony lies the arid and sparsely populated province of Little Namaqualand, separated on the north by the Orange River from the now German territory of Great Namaqualand. The sole harbour on its inhospitable coast is Port Nolloth, which affords shelter only to small vessels; and practically its sole industry is the raising and exporting of its ore. The coast districts are very sandy, and would probably be desert under any circumstances; but the aridity of much of the interior, like that of the so-called Kalahari Desert, is due to its extreme rainlessness, and the flora has adapted itself wonderfully to these conditions. It remains dormant during many successive seasons of dryness, until the moisture of one favourable summer enables it to cover with verdure miles of country that had seemed absolutely desert. On my journey eastward the plains showed no trace of vegetation save low, scattered, withered-looking bushes. But on that day there were a few slight showers of rain—snow on the higher region round Concordia—and on my return, six days later, the red soil was already covered with a thin growth of pale green herbs, with here and there a red or yellow flower. The dryness of the country is but ill represented on many of the maps, which show several large rivers running into the Atlantic. Port Nolloth stands at the mouth of one such about fifty miles long, but it is a very unobtrusive stream, and I do not recollect observing it on the spot. Most of the cartographers' rivers I am afraid are like the deceitful brooks of Syria, flowing only after the infrequent thunderstorms, and soon losing themselves in the sand.

About eighty miles inland are the mines of the Cape Copper Company and the Namaqualand Copper Company. At the beginning of August 1889, I was enabled by the courtesy of Mr Phillips, the Superintendent of the former Company, to spend a few days in this somewhat out-of-the-way district. The country has long been known to be copper-bearing, and about two hundred years ago Simon van der Stell, the Dutch governor of the Cape, led an expedition to explore it. But the difficulties of transport were so great that it has only been

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within the last forty years that anything has been done to develop its mineral wealth. The two Companies mentioned above export more than 30,000 tons of copper ore yearly, which may be taken as roughly equivalent to nearly 9,000 tons of the metal. All the ore goes to Swansea in sailing ships, and is there smelted. Most of the workmen are natives—Namaquas, Damaras, Hottentots, &c.—while the more important posts are usually filled by Cornish and Devonshire men.

Since I saw this district I have endeavoured to obtain the descriptions of former visitors, but I have not been very successful. Most of their reports appear to be buried in the pigeon-holes of the Cape Government. The most detailed description I have found is contained in a paper by Dr R. N. Rubidge in the Q.J.G.S. for 1857. He however mentions only some half dozen minerals from this district; Scheelite, "in a lump of about a pound weight . . . enclosed in a mass of red oxide of copper," being the only one I have not seen.

Around Port Nolloth, which consists of a single row of houses, and for some distance inland, nothing is to be seen but sandhills, rippled by the wind and dotted over with dwarfed bushes. These I believe were more plentiful formerly, but in the absence of any other fuel they have been rooted up and burned. I walked for some distance along the shore to the north of the bay, but found little of interest beyond traces of copper in the much crystallised quartz veins of the highly inclined rocks exposed along the beach, and what was apparently an aboriginal "kitchen midden," with flint flakes, heaps of broken shells, and one or two of the stone hand hammers with which they had been pounded.

The sand on the shore emits a musical note when rubbed like the well-known "Cheeping Sand" at Lag Bay in Eigg. Hugh Miller in his "Cruise of the 'Betsy'" refers to a similar sonorous sand in Arabia, and the phenomenon is by no means so rare as has been supposed. Besides Port Nolloth I have observed it myself at such widely separated localities as Madagascar, Sydney Harbour, and Monterey in California.

The morning after I reached Port Nolloth I left early for Concordia, the headquarters of the Namaqualand Copper Company. The carriage was drawn along the railway by a team of mules at the rate of ten miles an hour. As we got inland the soil improved, and there was a more varied though still excessively scanty vegetation. Fifteen miles on, the line passes between two apparently gneissic hills at Ogrebis Poort, and enters upon a long plain with hills on each side, and sloping gently upward to the east. This too was only scantily dotted with bushes. The line then turns southwards, and ascending

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some 1500 feet in the next six miles (a steam engine for this part of the journey taking the place of the mules) reaches a comparatively level plateau, from which rise ridges and single hills of brown rock with broad flats between. Many of these valleys show no trace of the presence of running water: in others there is the shallow bed in which a stream flows, it may be once in several years. The only tree to be seen anywhere in this part of the country is a large branched aloe (*A. dichotoma*), with a stout trunk some 18 inches in diameter.

There are a few springs scattered over the country, many of them, as might be anticipated, mineral to a greater or lesser extent. One of them—Grysfontein—is passed by the railway. It is slightly chalybiate and deposits sulphur, issuing from a clayey and, at the surface at least, much decomposed shale.

The country rock at Concordia is a much jointed and disintegrated gneiss, granitic in some places, and in others highly schistose. It is generally very tough, and many of the loose blocks give a clear metallic ring when struck with a hammer.

The gneiss is intersected by veins of quartz and decomposed felsite. The veins of the main system are quartz and run east and west. The quartzose or felsitic cross-courses run approximately north and south and dip to the east. In the Concordia property two cross-courses cut the lodes in the mines—one at Wheal Julia, the effect of which cannot be ascertained, and one at Tweefontein, where the lode appears to be thrown north a few feet on the west side of a NNE. cross-course and a few feet south on the other side. The vein at Henderson's, on the other hand, seems to be thrown south some 30 yards by a NE. cross-course a little to the east of the old shaft.

The cross-courses are all barren, but several of the east and west veins are metalliferous. The outcrop of these veins is recognisable at a considerable distance by the red-brown staining of the rock caused by the oxidation and hydration of the contained magnetite, while close at hand the green copper stains are the usual indication. The lodes dip to the north about one in six, but the walls are not generally well defined. The metal occurs in pockets and small leads and strings, and sometimes merely spotted through the quartz.

The principal ores at these mines are Blue and Purple Copper (Bornite) and Yellow Copper (Chalcopyrite). They occur associated, but in some of the mines one and in some the other is the more frequent. Thus at Tweefontein, Ookiep, and Spektakel the ore is mostly Purple Copper, while at the Flat Mine it is yellow and of too low a grade to work profitably at present prices. Wheal Julia was principally Purple Copper and Hester Maria yellow, but these are now apparently

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exhausted. Many experimental shafts have been sunk in the various metalliferous veins of the district, but the first three mines above mentioned are the only ones at present being worked. Neither the Bornite nor the Copper Pyrites occur here crystallised, so far as I know.

Omitting those minerals which are merely constituents of the rock, the following species occur associated with the copper, or at least are found in the same mines:—

Molybdenite. In micaceous scales, and also in large folia.

Galena. Massive.

Chalcocite. Massive, rarely.

Pyrrhotite. At Ookiep East only. It occurs massive in considerable quantity in a dark gabbro. It contains a small percentage of Nickel, and is not very strongly magnetic.

Pyrites. Massive. In some parts of Namaqualand, as elsewhere in South Africa, it occurs in distorted cubes altered to *Turgite;* but I have not so seen it at the mines.

Quartz. Not infrequently in the ordinary terminated six-sided prism.

Cuprite and *Melaconite.* Formerly in great abundance at the outcrop of the lode at Wheal Julia, but now rare. The cuprite occurs also as *Tile ore.*

Magnetite. Massive, and very rarely crystallised. It is the most common impurity in the ores, and its elimination is attended with some difficulty. A considerable proportion is separated by passing crushed ore over a wheel armed with magnets. The magnetite adheres, and being carried round is removed by a brush.

Malachite. The stains at the outcrops of the lodes are not very easy to discriminate. They are probably mixtures of various cupric silicates and carbonates.

Pyroxene. In the form of a pale green translucent *Sahlite.*

Garnet. Pinkish. Species undetermined.

Epidote. Brownish green. In a small vein imperfectly crystallised with copper pyrites.

Laumontite. In minute brick-red crystals at the Flat Mine.

Biotite. All that I saw was much weathered.

Allophane. Various shades of brown and green. It is deeply coloured by copper, and it is often impossible without analysis to distinguish it from

Chrysocolla, which also occurs.

Erinite. Grass green mammillations.

Ehlite.

Clinoclase in radiated fibrous groups, with a very high lustre on the cleavage plane.

Brochantite. Groups of minute dark green crystals.

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Lettsomite. Occurs not infrequently, both globular and plumose.

For the identification of the five last minerals on this list I am indebted to the kindness of my friend Dr Heddle. As there have been no analyses, these five identifications must be considered provisional except in the case of the Lettsomite. Dr Heddle also identified the Laumontite, and confirmed my identifications of the remaining species. He also thought he recognised *Chalcophyllite*, but I have mislaid the specimen. I got one bit with minute dark green crystals very like *Atacamite*, and in one specimen from Springbokfontein I think I recognise *Zaratite*.

Where there is standing water in the deserted workings there is deposited a pale greenish blue mineral, which is doubtless a mixture of *chalcanthite*, *melanterite* and other salts.

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V. — *On Two Volcanic Necks in Applecross, Ross-shire.* By J. HORNE, H.M. Geological Survey of Scotland. (*Communicated by permission of the Director-General of the Geological Survey.*)

(Read 15th February 1894.)

IN the course of my official work in Applecross I observed two "necks" in the south-western part of the peninsula which evidently represent the roots of two small volcanoes. Situated on the 1000 feet plateau, and within two miles of the western shore, they pierce the gently-inclined beds of Torridon sandstone. Were it not for the bright verdure that clothes the surface of one of these vents, they would almost escape recognition amid the rocky escarpments and peat-clad dip slopes of the surrounding rocks.

Following the Toscaig river to a point about three miles from Toscaig Bay, it there receives a small tributary on the west side, flowing out of Lochan nan Slochd. This lochan lies along a line of fracture that has been traced for a considerable distance in a NNE. and SSW. direction; the course of the fault being indicated on the surface by a more or less prominent hollow. These necks occur close to, and on opposite sides of, this line of fracture. The more important of the two is situated on the western slope of this hollow, and at a distance of about 300 yards from the south end of the loch.

Ascending this slope, the observer finds an oval-shaped mass of volcanic agglomerate measuring about 180 feet from east to west, and about 150 feet from north to south. The escarpments of Torridon sandstone, which there run nearly north and south, may be followed close to the edge of the agglomerate, when they are suddenly truncated by this amorphous mass. On approaching the edge of the vent the sandstones assumed a bleached appearance, but the contact alteration is certainly not very pronounced. They are indurated and break with a splintery fracture, thus differing from the normal characters of the sandstones and grits.

With the exception of a small patch of basalt at the south end of the neck, it is filled with agglomerate varying somewhat in character. It is of a brownish colour on some weathered surfaces, but in a fresh fracture the matrix has a dull green or grey tint. The blocks embedded in the agglomerate are mainly composed of Torridon sandstone and grit, which are occasionally

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subangular, but more frequently oval-shaped. They are usually small, but some measure a foot across, and in one exceptional instance 4 feet by 2 feet. The alteration of the fragments of Torridon sandstone is not very prominent, but as a rule they have a bleached or paler tint than the normal grits of that formation: occasionally they have a glazed or vitreous appearance, and the quartz-grains are turbid or semi-opalescent. But in addition to these Torridon blocks there are abundant lapilli of a basic volcanic rock. A microscopic section of the agglomerate containing these basic lapilli is thus described by Mr Teall: "The lapilli vary considerably in size. They consist of porphyritic felspars, extremely minute acicular microlites of felspar, somewhat irregular transparent spaces, now occupied by a yellowish green substance, giving aggregate polarisation and interstitial matter which has been rendered opaque by the separation of ferric oxide. They are undoubtedly altered basaltic lapilli, and it is highly probable that the original base was of a glassy character. The matrix of the rock appears to consist of detached grains of the sandstone and the finer lapilli."

At the south end of the vent, and within the margin of the mass there is a small exposure—a few yards in extent—of highly decomposed basalt, so weathered that it is difficult to get a fresh specimen. It appears to pierce the agglomerate.

The second neck occurs on the east side of the fault already referred to, and about 500 yards from Lochan nan Slochd. Its relations are much obscured by a covering of peat, but along the northern margin of the vent there is a good exposure of coarse agglomerate resembling that just described; the Torridon blocks being of a larger size. Its eastern limit is defined by a small feature formed by the agglomerate, which is covered with peat or turf. At the south end, decomposing basalt is exposed in small scars, but its relations to the agglomerate are not visible.

There is no indication of the age of these two volcanic orifices. Basalt dykes occur in the immediate neighbourhood, and thin sills of the same material traverse the Torridon sandstone near Toscaig and Camasterach. From the nature of the matrix of part of the agglomerate, and the character of the basalt piercing the mass, it is not improbable that they may belong to some phase of the volcanic history of the West Highlands during the Tertiary Period. In the course of his inspection of my field work, Sir A. Geikie paid a special visit to the locality, and after examining the relations of these vents he was inclined to regard them as probably belonging to the Tertiary Period.

In his detailed description of the patch of Liassic strata at Applecross, Professor Judd calls attention to the fact that they are traversed by numerous basaltic sheets and dykes. He

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further states that "though it is highly probable that this patch of strata was originally buried under an accumulation of lava sheets, which have since been entirely removed by denudation, yet it is manifest that the great faults which have clearly let down these strata many hundreds, and perhaps thousands, of feet below their original level into the heart of the mountains of Torridon sandstone, have had much to do with their preservation." [1]

In 1874, the same author, in his brilliant paper on "The Ancient Volcanoes of the Highlands," has described a large neck of agglomerate in the peninsula of Ardnamurchan, forming the headland of Srone More or Maclean's Nose. The agglomerate breccia "contains numerous angular fragments of both the felspathic and basaltic lavas of earlier Tertiary periods, with some of the underlying gneiss, such being the rocks on which the mass of Bain Shiant is built up; mingled with these are numerous fragments of felspathic scoriæ and ashes, with many fractured and worn crystals of glassy felspar included in the mass.[2]

In his great monograph on "The History of Volcanic Action during the Tertiary Period in the British Isles" (Trans. Roy. Soc., Vol. xxxv., p. 107), Sir A. Geikie has described an enormous vent filled with agglomerate, about two miles in width, on the north side of the main valley of Strath, in Skye. He states that it has been so seriously invaded by the eruptive rocks of the group of the Red Hills, that its original dimensions and its relations to the surrounding rocks, especially to the bedded basalts, are much obscured. But it has been drilled through the Cambrian limestone, and, as the result of protracted denudation, it now towers steeply five or six hundred feet above that formation on the floor of the valley. He refers to the agglomerate as a coarse, tumultuous assemblage of blocks and bombs embedded in the usual dull, dirty-green matrix. Among the stones are amygdaloidal basalts, various quartz-porphyries, and large masses of altered Cambrian limestone and quartzite, and pieces of yellow sandstone and shale (Jurassic). The rock is wholly without structure or stratification of any kind.

From these descriptions it is evident that necks filled with volcanic agglomerate are a prominent feature of the Tertiary volcanic rocks of the Western Isles. Indeed, it is highly probable that others may be met with along the sea-board of the mainland between Applecross and Ardnamurchan.

[1] See Q. J. G. Soc., Vol. xxxiv., p. 672. [2] *Ibid.* Vol. xxx., p. 263.

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VI.—*The Intercrossing of Boulders in the Applecross Mountains.*

By J. HORNE, H.M. Geological Survey of Scotland.

(*Communicated by permission of the Director-General of the Geological Survey.*)

(Read 15th February 1894.)

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1. A study of the glacial phenomena of the south-western portion of the Applecross peninsula furnishes important evidence regarding the massiveness of the ice-sheet during the maximum glaciation, and the transport of boulders in opposite directions during successive stages in the history of that period. In the area north-west of Loch Kishorn there is clear proof of one set of boulders being carried up the valleys facing that loch and across the water-shed towards the Inner Sound of Raasay, while another set of local boulders has been borne down the same valleys by the later glaciers. Still more striking is the fact that foreign boulders have been first carried up and then carried down one and the same valley. Such phenomena bear a close resemblance to some of those described by MM. Falsan and Chantre in their great work on the ancient glaciers of the basin of the Rhone, where they attribute them to a change in the direction of the ice flow at different stages of the Ice Age.

2. The group of pyramidal mountains forming the southern portion of the Applecross peninsula rises abruptly from the shores of Loch Kishorn, and from the alluvial flats at the mouth of the Kishorn river, to heights varying from 2000 to nearly 3000 feet. Composed of gently inclined beds of Torridon

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sandstone, this range of mountains furnishes remarkable examples of the influence of parallel beds of strata in the formation of scenery. The gloomy corries and the deep narrow valleys are encircled by long lines of escarpment that in some instances tower for 1500 feet above the floor of the valley. An observer, stationed on the watershed between Loch Carron and Loch Kishorn, looking across to that noble group of mountains, is at first reluctant to believe that during the maximum glaciation the ice must have crossed Loch Kishorn and the river at the head of that sea-loch, ascended the valleys, and ultimately passed over the watershed in a NW. direction towards the Inner Sound of Raasay. And yet, from a consideration of the striæ and the transport of stones, such a conclusion seems inevitable.

The whole of the south-western portion of the peninsula was mapped by me in the course of my official work eastwards to the following boundary—viz., a line drawn from the head of Loch Kishorn north-west by Loch Coire nam Faradh to Allt Coire Attadale. The tract to the east of this limit, including Ben Bhan (2936 feet)—the most elevated part of the whole peninsula—was surveyed by my colleague, Mr Hinxman. The evidence obtained by him on that mountain is remarkable. Just underneath the 2750 feet contour line he found striæ pointing W. 20° N. and also W. 13° N., with an occasional block of Eastern Gneiss between that level and 2500 feet. Below the latter elevation erratics of Eastern Gneiss are fairly plentiful.

3. In the area examined by myself, on the col between Coire Attadale and Coire nam Faradh at a height of 2000 feet, the direction of the ice-markings is N. 21° W., and on Carn Dearg, between 1750 and 2000 feet contour lines, the trend varies from N. 41° W. to W. 41° N. Again, on the northern spur of Sgorr na Caorach at the same elevations, the markings point W. 23° N. and W. 34° N.

Proceeding westwards to the lofty plateau crossed by the road leading from Kishorn to Applecross, various striated surfaces are observable about a height of 2000 feet. The direction varies from W. 20°—43° N., but in some instances the local glaciers have partly effaced these earlier markings. For on the plateau above the zig-zag windings of the Applecross road there is a small corrie (Coire nan Clach) filled with a small group of local moraines and thickly strewn with boulders. The stream draining the western slope of the highest peak of Sgorr na Caorach (2539 feet) flows into this corrie. Now, close by the road excellent examples of cross-hatching are visible; the older set pointing W. 30° N., and the later or valley glacier

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markings S. 28° W. Similar evidence regarding the north-westerly flow of the ice is found on Crag Gorm at a height of 1750 feet, and when we pass westwards to Carn Chailean (1750 feet) the sandstone escarpments of that eminence are finely striated in a direction varying from W. 26° to 28° N.

On referring to the Ordnance Survey map of that region, it will be seen that the watershed from Ben Bhan, by Carn Dearg, Sgorr na Caorach, Meall Gorm to Carn Chailean, forms a sinuous line upwards of five miles in length, embracing the most elevated ground in the peninsula. And yet this lofty plateau has been striated in one general direction, varying from WNW. to NW., and in some rare instances to NNW.; the striæ being found at all levels from 1750 feet to 2750 feet. Confirmatory evidence can be gleaned from the glaciated sandstone surfaces that slope westwards to Applecross, Camasterach, and Toscaig. Even by the shores of Loch Toscaig the trend is W. 15° N., and near Calduie, close by Camasterach, it varies from W. 40° N. to N. 31° W. My colleague, Mr Peach, who mapped the greater part of the peninsula lying to the north of the midland valley, obtained similar evidence regarding the north-westerly flow of the ice. It is clear, therefore, that these north-westerly striæ belong to one general system, when the peninsula was glaciated in one determinate direction more or less independently of its physical features. Fortunately, by means of the transport of erratics, we are able to determine with certainty that the movement during this period of maximum glaciation must have been from the south-east towards the north-west.

4. Reference has already been made to the occurrence of blocks of Eastern schist and gneiss on Ben Bhan below the 2500 feet level. On the highest peak of Sgorr na Caorach, between the 2250 and 2500 feet contour lines, there are numerous fragments of deformed Lewisian gneiss, mylonised gneiss, thrust Torridon sandstone, slightly schistose and traversed with quartz-strings, with crystalline schists of the type of the Moine schist. One boulder—the largest noted, measuring about 12 cubic feet—is composed of crushed grey gneiss of the type occuring *in situ* north of Glenmore and north-east of Loch Kishorn. These foreign materials are very plentiful on the top of Carn Dearg, above the 2000 feet level, on Crag Gorm, and on the watershed southwards to Carn Chailean. They are specially abundant on the cols at the head of Coire nam Faradh and Alp a' Chumhaing—the two main valleys draining into Loch Kishorn. They are strewn over the rocky slopes northwards to the village of Applecross, and they occur in the fine boulder clay sections in Allt Mor that joins the Applecross river at Hartfield. They have likewise been traced over the north-western part of the peninsula by Mr Peach.

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5. The detailed mapping of the mountainous region of that part of the west of Ross-shire enables us to fix the sources from which these materials were derived. The blocks of deformed grey gneiss, mylonised Lewisian gneiss, and green and grey schistose Torridon sandstone, belonging to the lower division of that formation have been obtained from regions lying to the east of the great terrestrial movements in the north-west Highlands. My colleague, Mr Hinxman has traced the outcrop of one of these maximum-thrust planes from the shores of Loch Kishorn northwards, and then eastwards to Loch Carron. By means of this displacement a belt of deformed Lewisian gneiss and Torridon sandstone has been made to overlie the piled-up Cambrian limestone, quartzites, &c. Now the materials, consisting of deformed gneiss and schistose Torridon sandstone, that were transported by the ice across the south-western portion of the Applecross peninsula *must have been derived from the displaced masses east of this thrust-plane between Kishorn and Loch Carron.* The crystalline Moine schist occurs *in situ* to the east of the deformed Lewisian rocks, at the village of Loch Carron; while the main outcrop forms the mountains to the east of Auchnashellach and Strathcarron stations. Nowhere within the region of Applecross are rocks of these lithological characters to be found *in situ.* It is thus apparent that the evidence derived from the transport of erratics is in accordance with that of the striated surfaces and *roches montonnees.*

Further evidence, though negative, might be adduced that the ice movement during the maximum glaciation must have been towards the north-west. At the mouth of the Applecross river there is a small outlier of Lias limestone and shales which has been minutely described by Professor Judd.[1] Now, if the movement had been from the north-west, blocks of these fossiliferous rocks would assuredly have been found to the south-east of the limits of the outlier. But not a single boulder of these materials has yet been found on the rocky slopes that stretch south-eastwards to the watershed.

6. Before proceeding to describe the distribution of materials by the later valley glaciers, we might pause for a moment to consider the probable cause of the deflection of the ice-sheet towards the north-west in Applecross, and the light which it throws on the question of the thickness of the *mer de glace.*

From the western headlands of Applecross, an observer sees the smooth cones of the Red Mountains and the serrated peaks of the Coolins in Skye, rising to 3000 feet in height; while far away to the north extends the plateau of the bedded basalts. It is a well-known fact that the present average rainfall in

[1] See Q. J. Geol. Soc., Vol. xxxiv. p. 672.

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Skye is excessive, and it is now generally admitted that those regions where the present rainfall is abnormal may have been coincident with excessive precipitation of snow during the glacial period. If this reasoning be correct, then it is not improbable that during the greatest extension of the ice Skye may have been buried under a thick icy covering. The presence of this opposing force would undoubtedly exercise some influence on the ice radiating from the mainland. The latter in that portion of Ross-shire would follow the path of least resistance, which would be north-west towards the Inner Sound of Raasay.

7. It seems to me that the foregoing evidence regarding the north-west movement in Applecross points to an enormous thickness of the icy covering on the mainland. When such an isolated group of lofty mountains was over-ridden by the ice, after crossing Loch Kishorn and the glen at the head of that sea-loch, it is obvious that no system of valley glaciers can account for such phenomena. My colleague, Mr Hinxman, informs me that the top of Rhuadh Stac (2919 feet), on the eastern side of Glen Kishorn, is finely striated; the markings trending W. 25° N. He has further observed that the summit of Meall a Chinn Dearg (3095 feet) composed chiefly of Torridon grits and sandstones, is covered with transported blocks of Torridon sandstone and Cambrian quartzite. These are certainly remarkable facts. Indeed, when they are viewed in connection with the evidence in Sutherlandshire, where it would seem that the ice-shed during the extreme glaciation lay to the east of the present water-parting; and with the evidence in Applecross, where a group of mountains rising from the sea-level to nearly 3000 feet has been overtopped by the ice, the estimate of the thickness of the Highland ice-sheet given by Sir A. Geikie does not appear to be excessive. In the latest edition of his text-book, he says: "Many mountains in the Scottish Highlands show marks of the ice-sheet at heights of 3000 feet and more. If to this depth we add that of the deep lakes and fjords which were filled with ice, we see that the sheet could not have been less than 5000 feet thick in the northern parts of Britain."[1]

8. Brief reference must now be made to the transport of materials by the local glaciers in the two main valleys draining the slopes of these mountains towards Loch Kishorn. One of these is traversed by the Allt na Fraoich (Burn of the Heather), which, rising in Coire nam Faradh on the col between Ben Bhan and Sgorr na Caorach, discharges into the sea at the head of Loch Kishorn. The other

[1] See "Text-Book of Geology." Sir A. Geikie. Third edit., 1893. p. 1027.

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is watered by Allt a' Chumhaing, which drains the corries between Meall Gorm and Sgorr na Caorach.

Below the limits reached by these two valley glaciers, the ice-markings are marvellously fresh, and in almost all cases they seem to indicate a movement towards Loch Kishorn.

From the mouth of the latter stream, along the shore, westwards by Airidh-drishaig to within a mile of Uaigs, a distance of five miles, the striæ are running more or less parallel with the coast. Whether these may indicate an "undertow" of the ice-sheet during the extreme glaciation, or merely a shrinkage of the ice moving parallel with the sea-loch, it is difficult to say. It is not improbable that the former view may be the correct one for reasons which cannot here be given.

The upper limits of the Coire nam Faradh glacier are well defined by the splendid lateral moraines. On the west side of the loch of that name (see 1-inch Ordinance map) there is a prominent group of crescent-shaped moraines at a height of several hundred feet above the loch, that form continuous ridges curving towards the centre of the valley. Each ridge, along its upper limit, "tails off" against a prominent escarpment of Torridon sandstone, and is strewn with boulders of that formation derived from the magnificent cliffs on the west side of the valley. At this point the local glacier must have been 500 feet thick.

The eastern limit of this glacier is defined by a great lateral moraine traceable for half a mile from the sea-level at Loch Kishorn up the slope of Ben Bhan.

That the glacier descending from Coire nam Faradh coalesced with that in the adjoining valley to the west as they approached the sea-level is highly probable from the behaviour of the moraines. Long lines of boulders mark the course of these glaciers towards Loch Kishorn. They are very conspicuous on the ground between Russel and the mouth of Allt a Chumhaing. At the latter locality concentric lines of moraines and trains of boulders may be traced from the sea-level up the slope west of the stream to the rocky escarpments of Meall Gorm.

Now, a careful examination of the various sections of moraine matter shows that the materials, with few exceptions, have been derived from the cliffs of Torridon sandstone in the respective valleys. The massive erratics forming the parallel lines of boulders have been carried for some distance down these valleys. There are, however, occasional ice-worn fragments of crushed Lewisian gneiss, mylonised gneiss, and schistose Torridon sandstone in the moraine matter; and I observed one or two larger blocks of crushed gneiss perched on the moraines on the slope west of Loch Coire nam Faradh. These materials were

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distributed, as we have seen, during the great glaciation, and the debris must have fallen on to the surface of the later glaciers, and must have been carried down to lower levels, thus performing a double journey. It is a significant fact that above the limit of the valley glaciers on the southern slope of Sgorr na Caorach, at levels ranging from 700 to 1000 feet, the debris of deformed Archaean gneiss, &c., derived from the east of Kishorn, seems to be more abundant than in the moraine matter distributed by the later glaciers.

9. We might now summarise the evidence given in the foregoing pages regarding the successive stages of the Ice Age in Applecross.

First. It is probable that before the extreme glaciation of that region these lofty mountains had their local glacier systems flowing from the high corries towards the sea-level.

Second. As the cold increased and the region became enveloped in a continuous sheet of ice, this local flow was arrested, and the Applecross peninsula was glaciated in one determinate direction towards the north-west. During this stage in the history of the period, erratics of deformed gneiss and schistose Torridon sandstone were transported from the ridge between Kishorn and Loch Carron, across the elevated plateau of Torridon sandstone to the shores of the Inner Sound of Raasay.

Third. When the *mer de glace* had declined or disappeared, local glaciers again supervened, bearing local boulders down the valleys to the shores of Loch Kishorn.

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VII.—*A Triassic Land-Surface.* By EDWARD GREENLY, F.G.S., H.M. Geological Survey.

(Read 15th March 1894.)

1. THERE are few subjects in Geology more fascinating than the study of the physical features of the earth's surface in remote periods of its history. Such studies are perhaps usually successful when pressed no further back than Post-Tertiary or Pliocene time, since which in our islands, the development of their scenery has proceeded continuously on the same general lines, in spite of the severity of the Glacial episode. But the scenery of periods so remote that since their time great earth-movements have occurred (and all, or nearly all, of the British area has been submerged, and buried under fresh loads of sedimentary rock) can, for the most part, be but dimly imagined, and we find that the bare outlines of land and water, and that, too, in the vaguest generalities, are all we can discern.

So much has been obliterated by waste, so much lies yet deeply buried; and the very lie of high and low land is so easily distorted by even a very moderate movement of the earth's crust.

Still, the preservation of scenery is a question of accident rather than of age; as is strikingly shown by recent discoveries in the Torridon Sandstone in the north-west Highlands, and also in certain portions of the Old Red Sandstone in Scotland.

A happy concurrence of circumstances has given us a glimpse of an episode in the scenery of the Triassic Period in the region that is now North Somerset, and to this I propose to draw your attention this evening.

2. This region is composed of Upper Palæozoic Rocks, from the Old Red to the Coal Measure inclusive, a total of about 14,000 feet; and of upper Trias or New Red Marls, Rhætic Beds, and Lower Lias about 1000 feet.

Between the Palæozoic and Mesozoic series there is a violent unconformability, the older rocks being affected by powerful folds with a vertical amplitude of several thousand feet, and also by large faults (some of which are certainly over-thrust faults); while the later rocks are affected by none of those movements, and lie upon the denuded edges of the others, with only a general low dip to the south-east, at angles so low as to be often horizontal to the eye in any one section.

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The Carboniferous Limestone always forms the most striking hill-scenery. It is from 2000 to 3000 feet thick, and is scarcely broken up by any important shaly zones, but is composed of massive, jointed, limestone for hundreds of feet at a time.

The Old Red and the Coal Measures are less resisting, but the Palæozoic rocks as a whole are far harder than the Secondaries, and very much more so than the New Red Marl, which is very soft and crumbly, with very little in it even of soft sandstone. The only hard member in the Dolomitic conglomerate, which is always closely related, in a certain sense, to the Carb. Limestone. It is a coarse angular conglomerate or breccia, with blocks (sometimes very large) of Carb. Limestone, and sometimes other Palæozoic rocks, set in a ferruginous and dolomitic cement.

3. Now, the region which yields the evidence is that in which the older rocks are still partly covered with Triassic Marl; between the wholly Palæozoic areas to the west and south, and that to the east, when the Jurassic beds descend to the sea-level; a rough Trapezium bounded by the Avon below Bristol, the channel from Avonmouth to Brean Down near Weston, the south side of the Mendip Hills, and a line joining Wells and Bristol, but curving to the west of an outlier of Inferior Oolite at Dundry—about 70 or 80 square miles. Within this area Highland and Lowland are very sharply marked off from each. From high breezy downs and ridges covered with short turf, and here and there cut by deep coombes of gray limestone crag, we can gaze across spaces of low undulating orchard or pasture, or, with a more striking contrast still, over miles of perfectly flat alluvium (carses, they would be called in Scotland) rich pasture, stippled with innumerable trees and hedges, ranging right away to the shores of the Channel.

The hills are for the most part about 400 or 500 feet high, except the great range of the Mendips, which reaches the 1000 contour.

Besides this, and the broad auticlinal tract of Wrington Warren, there are six well-defined, escarpmental ridges of Carb. Limestone, running E. or ENE. Every range of hills is composed of Palæozoic rocks, and every valley of Trias Marl (except a low synclinal tract of Coal Measures at Nailsea, from which the Trias can only have been stripped just before the deposit of the alluvium that now covers it); and nothing could be more striking than the contrast between the two. Islands could hardly rise more abruptly from the sea than the hills from these low tracts of marl and alluvium.

4. Now, let us consider the results of the great earth movements which set in at the close of the Carboniferous period.

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The older parts of these rocks plunged deep below the base level of denudation of that time in the synclines; while, rising upon the great anticlines, they became exposed to waste. The *pièce de resistance* was the Carb. Limestone, so that when it came up on an anticline it delayed denudation, while the softer Coal Measures were removed partially even from the synclines, thus furnishing an exception to the general rule that geological depressions correspond with geographical elevations.

Then subsidence set in. Water crept up along the valleys, covering the low Coal Measure tracts, while the limestone hills still stood out above them till these hills became islands, separated by shallow straits and channels.

Into these channels were carried the products of the never-ceasing waste, fine red mud, calcareous from the waste of the masses of limestone, with occasional beds of sand, deposited perhaps during stormy seasons, but all full of salts, and barren now of fossils. Close to the steep sides of the sinking islands crumbled down the coarser debris, angular screes from their crags apparently, which the waters of the narrow channels had barely force to roll into pebbles—only to spread out a little further than they would have been carried by gravity alone; and these wedge-shaped beds are the Dolomitic Conglomerate, cemented by the mineral deposits of the salt Triassic sea. It comes in at all horizons in the Trias, so long as any limestone island steep enough to furnish it remained above water. Then, as the valleys silted up, the hills themselves were submerged, and finally the more open sea of the Rhætic-beds and Lias crept over both the red valley silts and the crowns of the buried hills, and the ancient scenery became sealed up within a maze of Mesozoic sediments.

5. This complex of Palæozoic and Secondary rocks has been the block on which Post-Tertiary denudation has been at work, but it has been worked upon in an inclined position. From the region to the west, the later deposits, lifted high, have been completely removed. Upon the eastern area they still remain in an unbroken spread, because their base lies below the level accessible to denudation. In North Somerset the base level of denudation almost exactly coincides with the average level of the bottoms of the old valleys. And so, in that region, the Lias and Rhætic-beds have been removed, and, after them, the Trias marls in the same way as, only with even greater ease, than the Coal Measures of old. But after the lapse of unknown ages the Carboniferous Limestone remains as great an obstacle to erosion as ever, and from the moment when the eroding agents tapped the summits of its buried hills, a selective action set in, and they found it so much easier to wash away the soft red marls

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from the sides, that the flow of water was once more guided into the ancient tracks, and began to scoop out a second time the choked-up channels.

Valley after valley began again to see the light of day, ridge after ridge to stand out into the air, little changed in form from what they must have been towards at any rate the *close* of the elder period, as is shewn by the patches of Rhætic-beds still lying here and there upon them. Changed they very likely are from what they were in the *earlier* part of the period of Triassic waste, for during that time they must have lost in height and perhaps in ruggedness to *some* extent, and marine erosion could not fail to tell upon their summits at their final subsidence, comparatively rapid though that subsidence must have been. Still, their present form must be very nearly the same, their distribution exactly the same, as at the time when the shallow waters of the Trias lay between them in straits and channels. And our imagination is aided by the accident of a very recent spread of waters in these same channels, which has laid level spreads of alluvium on their undulating floors.

So that it needs but little effort, standing on the steep hills of Clevedon or the Mendips, to substitute for

> that great plain
> That sweeps with all its autumn bowers,
> And crowded farms, and lessening towers,
> To mingle with the bounding main,

the rippling waters of the ancient channels, or their tracts of red muds, drying and cracking in the sun, and stalked over by gaunt reptilia, and the hills, not green as now, but most likely arid and parched, and tenanted by creatures no higher than the first little marsupials, the small beginnings of mammalian life.

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VIII.—*The Glaciation of the West of Scotland, with Special Reference to the Theory of Floating Ice.* By Mr DUGALD BELL, F.G.S., Associate Edinburgh Geological Society.

(Read 15th February 1894.)

[*Abstract.*]

HAVING described the various traces of ice-action in the neighbourhood of the Firth of Clyde, and pointed out the directions in which it was evident the ice moved, as also the proofs of the great mass and volume to which it attained, the author passed on to consider the theory which had lately been supported in certain influential quarters, that the agent which produced these effects was in the form of floating ice, or "ice-floes." With all respect to those who hold this theory, he showed in some detail that it is inconsistent with the characteristics of the phenomena they had been considering, viz., the striation of the rock surfaces, the distribution of boulders, and the composition of the boulder-clay. Besides, this theory requires, quite as much as the old theory of icebergs, the action of marine currents, and these again imply a deep submergence. Following the course of these supposed marine currents, from the central valley of the Clyde, it was shown that marks of them all, by different channels, led to the mountainous tracts of Dumbarton and Argyll-shires, from which they appeared to radiate in all directions. Of course, with marine currents this was impossible. The distribution of boulders, particularly those of granite, confirmed what had been stated, and showed that the agent could not have been ice-laden currents, but must have been great streams or sheets of land-ice. Further, the submergence which the theory under notice required would leave very little of the country above water; too little for the formation of "floes" of any extent alongside of it, or for the accumulation thereon of great quantities and varieties of rocky debris. Not only so, but such a submergence, by diminishing or abolishing the high lands, and admitting more freely the ocean-currents, would in all probability, as Lord Kelvin had shown, be attended by mild conditions of climate far up into northern latitudes. Thus the submergence which

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the ice-floes required in one way, seemed fatal to them in another. In conclusion, the author deprecated having recourse to great changes of the earth's surface within comparatively recent times, for which there was really no sufficient evidence; and alluded to the wise caution of Darwin, who could say with some satisfaction that he had "never elevated or depressed Mother Earth in order to account for any one phenomenon."

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IX.—*Petroleum and Natural Gas: their Geological History and Production.* By HENRY M. CADELL of Grange, B.Sc., F.R.S.E., *Hon. Secretary.* (*With Diagram, Plate II.*).

(Read 19th April 1894.)

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INTRODUCTION.

So much has already been written on the occurrence of liquid and gaseous hydrocarbons, since their discovery on a commercially important scale less than fifty years ago both in the Old and New Worlds, that it may seem superfluous to add to the mountain of literature already existing on the subject. It has, however, occurred to me that as the subject is one of such general interest, and the petroleum industry is undergoing rapid developments every year, there may still be room left in Scotland, at least, where the mineral oil industry is a source of much scientific and economic enterprise, for describing in concise form some of the more salient characteristics of these natural products as they occur in other lands. It has also struck me that my ignorance of the geology of petroleum and natural gas, previous to my visit to the American oil regions in 1891, may be to some extent shared by readers who have not had the time or the opportunity to investigate the subject for themselves or wade through the writings of those who have made it a matter of special study. I propose, therefore, to describe briefly in the

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following pages the results of some of the more important investigations into the geology of these valuable sources of energy, dealing with the theories as to the origin of natural oil and gas, their geological and geographical distribution, and the scientific and practical results of their discovery and development.

In the limited space at my disposal it is, of course, only possible to touch the very outskirts of such a vast subject, and anyone who wishes to go into greater details will find a valuable store of material in Prof. S. F. Peckham's "Report on the Production, Technology, and Uses of Petroleum and its Products," published in 1885 by the Department of the Interior Census Office, Washington. This volume contains a catalogue of the literature on the subject up to 1880.

1. Source of Natural Hydrocarbons.

The original source of hydrocarbons in the stratified formations of the earth's crust is, apparently, the organic remains of former inhabitants entombed in these deposits. The question is, By what process of decomposition and rearrangement have these substances been brought into their present simple chemical state, and stored in such a way as to burst forth in vast quantity in certain regions and under certain geological conditions? The question is as much a chemical and physical as a geological one, and to solve it we must often have recourse to other than purely geological methods of investigation.

Petroleum and natural gas have a very wide distribution, both geographically and geologically, as they are found over wide areas in America, Eastern Europe, and Asia; while their geological range extends from the Lower Silurian up to the Tertiary system. It is thus clear that the physical conditions under which oil has been produced have prevailed at many places and periods in the world's history, and hence it is quite reasonable to suppose that there may have been differences in the exact process by which the same ultimate result has been arrived at, just as there have been variations in the precise manner of formation of many of the coal deposits in different countries.

2. Geographical Distribution.

Before dealing with the geology of petroleum, it may be of interest to note the chief countries and places where it is found in commercial quantities.

The principal sources of supply of rock oil are at present Russia and the United States, and especially the region extending from New York State south-westwards past Lake Erie, along

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the western side of Pennsylvania and Virginia, through Ohio and Kentucky to the centre of Tennessee,—a broad zone somewhere about 700 miles in length, in which the majority of the productive wells of America are situated. Petroleum has, however, also been found in limited quantities to the west of this tract in Indiana, Illinois, and the southern part of Michigan, while on the Pacific Coast several productive wells have been found northwards from Los Angelos in California. Isolated wells have been found in Alabama, Kansas, Louisiana, and a few other States, but the great bulk of the American oil is derived from the zone first described.

Some small oil fields are also found in Canada, the most productive of which lie within an area of about 11 square miles at the township of Petrolia in Western Ontario. Both solid and liquid forms of bitumen occur in numerous other parts of the New World, such as Mexico, the West Indies, Peru, and Venezuela; and in the Island of Trinidad there is a lake of pitch about 3 miles in circumference, which constitutes apparently the largest deposit of asphaltum in existence, and affords an inexhaustible supply of that useful form of solid hydrocarbon.

In the Old World by far the most important oil regions hitherto discovered are those of the Caspian, where the majority of the wells lie within a radius of 20 miles of the City of Baku. Petroleum is, however, also found in limited quantities in Europe, along the flanks of the Carpathians and the shores of the Adriatic, as well as in Denmark, and a few parts of France and Germany. In 1883 I visited a district at Oelheim near Peine, in the Duchy of Brunswick, where oil had been struck, and as the place resembled on a miniature scale one of the great American oil fields, with its forest of derricks, walking beams, and wooden shanties, it had been nicknamed the "New Pennsylvania," but the quantity of oil was very limited and had to be obtained by pumping, none of the wells at the time of my visit being of the valued flowing class.

Small quantities of petroleum are occasionally found in Scotland in connection with the oil shales of the Lothians, the "Balm Well" of St Catherine's, near Edinburgh, being a well-known example. While quite recently oil has been found in Somerset, but in quantity far too small to be of economic value.

Solid and liquid hydrocarbons are found in parts of Asia in considerable quantities. The Dead Sea or Lake Asphaltites is surrounded by deposits of asphaltum—the slime pits of the Bible—and during earthquakes masses of this substance, like small islands in size, rise to the surface and float on the dense waters. Bitumen and petroleum springs occur in Persia along

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the Valley of the Euphrates and Tigris, while natural gas and oil issue from the ground at various parts of Thibet and Northern India, where the gas is burned in the Hindu temples. China appears also to have yielded petroleum at some places, while the natural oil industry of Japan has been carried on for more than 1200 years, and large numbers of wells were sunk before the great increase in the production of American oil put an end to the profits of that ancient business.

Petroleum has been found in Burma, in Java, Borneo, and other islands of the Indian Archipelago, and is also known to occur in Australia and New Zealand at a few places. As the more remote regions are opened up it may be expected to be found over still wider areas, but at present we may note that both in the Old and New Worlds the greatest oil regions occur along the flanks of some of the chief mountain ranges. The great oil belt of the States runs alongside of the Appalachian uplift, while those of the Old World follow the lines of the Apennines, Carpathians, and Caucasus, and the mountain chains in Palestine, Indo-China, and Japan.

3. Geological Distribution.

I have mentioned that solid and liquid and gaseous hydrocarbons are found in all formations from the Lower Silurian to the Tertiary, but by far the greatest quantity of petroleum is at present obtained from strata of Silurian, Devonian, and Lower Tertiary age, comparatively little having as yet been found in the later palæozoic or secondary formations of the Old or New Worlds.

Oil and gas are found in Canada, New York, and Ohio through a vertical succession of strata extending from the middle of the Carboniferous to the Trenton limestone of Lower Silurian age. The thickness of this immense succession of beds is, of course, very variable, but, roughly speaking, may be averaged at something like 6000 feet. It includes the lower productive coal measures, the thick Devonian shales and oil-bearing sandstones, the oil-bearing corniferous limestone at the base of the Devonian beds, the Upper Silurian shales, and Niagara limestone, and the Lower Silurian shales with the underlying Trenton limestone, which ancient horizon was, in 1887, found to yield the supplies of oil and gas now being obtained in Ohio and Indiana in enormous quantities.[1]

The following table, taken partly from Mr Joseph D. Weeks'

[1] For a detailed account of this subject, see Mr Edward Orton's elaborate paper on "The Trenton Limestone as a Source of Petroleum and Inflammable Gas in Ohio and Indiana," published in the Eighth Annual Report of the U.S. Geol. Survey, Washington, 1889, pp. 477-662.

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paper on "Petroleum in 1892," and partly from Charles A. Ashburner's paper on "Natural Gas,"[1] gives a generalised list of the palæozoic formations in New York, Pennsylvania, and Ohio, as now commonly accepted by American geologists:—

	No.	
Carboniferous.	XVII.	Greene County Series=Upper Barren Coal Measures of Ohio. From surface to top of Washington Upper Limestone.
	XVI.	Washington County Series=Upper Barren Coal Measures. From top of Washington Upper Limestone to top of Waynesburg Sandstone.
	XV.	Monongahela Series=Upper Productive Coal Measures. From top of Waynesburg Sandstone to base of Pittsburg Coal.
	XIV.	Pittsburg Series=Lower Barren Coal Measures. From base of Pittsburg Coal to base of Mahoning Sandstone, in which small quantities of oil have been found.
	XIII.	Allegheny Series=Lower Productive Coal Measures. From base of Mahoning Sandstone to top of Homewood Sandstone, including the Freeport, Kittaning, Brookville, and Clarion Coals, but producing no oil.
	XII.	Pottsville Series=Pottsville Conglomerate. From top of Homewood Sandstone to base of Olean Conglomerate, in which oil occurs in uncertain quantities.
	XI.	Mauch Chunk=Sub-Carboniferous Limestone of Ohio. From base of Olean Conglomerate to top of Sub-Olean Conglomerate. Unimportant as to oil.
	X.	Pocono Series=Waverley Series of Ohio. From top of Sub-Olean to top of Venango-Butler Oil group, including the Shenango Sandstone, Big Injun Oil Sand, Berea Grit, Pithole Grit, and Logan Sandstone and Conglomerate, from which oil and gas are obtained in considerable quantities.
Devonian.	IX.	Catskill Series=Old Red Sandstone, absent in Ohio. Includes the Venango-Butler Oil group, the great oil-producing horizon of Pennsylvania.
	VIII.	Chemung Sandstone and Shales=Ohio Shale. Portage Sandstone and Shales=Cleveland, Erie, and Huron Shales.

[1] Read before the American Institute of Mining Engineers, St Louis, 1886.

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	No.	
Devonian.	VIII.	Genesse Shales and Slates.
	contd.	Tully Limestone.
		Hamilton Sandstones and Flags.
		Upper Helderberg Limestone = Corniferous Limestone of Ohio. From base of Venango-Butler to top of Oriskany Sandstone, including the oil and gas sands of M'Kean, Warren, Forest, and Elk counties of Pennsylvania; oil-producing horizon of Canada.
	VII.	Oriskany Sandstone (absent in Ohio).
Upper Silurian.	VI.	Lower Helderberg Limestone.
		Waterlime.
		Salina and Niagara Shales and Limestones.
	V.	Clinton Shales = Clinton Limestone of Ohio.
	IV.	Medina Sandstone = Medina Shale of Ohio.
		Oneida Conglomerate.
Lower Silurian.	III.	Hudson River Shales = Cincinnati Series of Ohio.
	II.	Trenton Limestone Series = Trenton Limestone of Ohio. Rich in oil and gas in Ohio.
	I.	Potsdam Sandstone = Potsdam.
		Acadian Series.
		Archæan.

The great oil wells of the Caspian are found in loose sandstones or coarse sand-beds, apparently of Eocene age, as has been already mentioned, under conditions differing greatly from those of America. The natural hydrocarbons in California occur in highly inclined strata which are also of Tertiary age, and the Californian oil-fields differ in many respects from those of the Eastern States, one important difference being that they have asphaltum instead of paraffin as their base, and are more important as fuel than as illuminating products.

4. Composition of Petroleum.

The term "petroleum," or "rock oil," like "natural gas," relates to the origin rather than the composition of the substance. It denotes a mixture of several fluid or solid hydrocarbons and other substances which are associated with one another in very variable proportions. Generally speaking, these constituents, whose specific gravity together is about 0·80, are divided into four classes, into which crude petroleum is separated during the refining process. These are—

1. Naphthas, or the lighter hydrocarbons, of sp. gr. about 0·7.
2. Light illuminating oils.

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3. Heavy lubricating oils, sp. gr. 0·84 to 0·91.
4. Residuum, consisting either of paraffin or asphaltum.

The petroleums of Pennsylvania yield on the average 10 to 11% of naphtha, 75 to 78% of illuminating oil, 2 to 6% heavy oil, 2¾ to 4% of residuum, and 5 to 8% of water (loss). The term "kerosene" is sometimes used for the lighter illuminating oils, and includes a somewhat widely varying class of the more inflammable products of the distillation of petroleum, lightness in colour and specific gravity being their common characteristic. The flash point of kerosene, the standard of which has given rise to much discussion both here and in America, is the temperature at which the oil gives off inflammable explosive vapour, a temperature considerably below that at which the oil can be itself ignited. The flash point is low in proportion to the percentage of naphtha, which is itself highly inflammable, and unless carefully separated renders lamp oil very dangerous for domestic use. All burning oils which have a flash point of less than 100° F. are dangerous, as lamps, especially if made of metal and used in a hot room, have been found to reach a temperature varying from 85° to 125° F., and in many cases disastrous explosions have resulted, especially with the worse constructed kinds of lamps. For the safety of the public, it is therefore clear that the only way to prevent possibility of explosions is either to prohibit by law the sale of illuminating oils with flash point under 100° F. for domestic lamps, or at least to compel merchants to let purchasers know the exact flash point of the oil they buy, so that the responsibility will rest on the buyer alone. A great deal of the American illuminating oil sold here has a flash point of 70° F., and the best Russian 86° F., while much of the Russian oil flashes at considerably lower temperatures, so that it is full time our Legislature took steps to enforce the higher standard, and enable us to use oil lamps without constant and unnecessary risk of explosions.

The average percentage of commercial products obtained from the crude petroleum of 45° Beaumé, or 0·800 sp. gr., of New York, Pennsylvania, Ohio, and West Virginia, is as follows :—[1]

Gasoline	1 to 1·5
"A.," "B.," and "C." Naphthas .	14·5 „ 15·0
Illuminating Oil . . .	50 „ 54·0
Lubricating „ . . .	17·5
Paraffin Wax=4½ lbs. per barrel .	2·0
Loss	10·0
	100·0

[1] Peckham, p. 165.

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5. The Origin of Petroleum and Natural Gas.

This subject, it need hardly be said, has given rise to much controversy and theorising.

The discussion has been taken up by chemists and geologists alike, each regarding it from the standpoint of his own department of science. The subject divides itself naturally into two parts. The first deals with the origin of the fluid and gaseous hydrocarbons, and the second with the reason of their present physical distribution.[1]

The chemists who have investigated the matter have put forward two main theories, the first of which refers the hydrocarbons to a purely mineral origin, and the second to the agency of organic matter as the primary source from which they have been derived. It is needless to discuss the first or purely chemical hypothesis, which supposes the hydrocarbons to be due to the chemical action at high temperature of the alkali metals on carbonic acidulated water deep down in the earth's crust, as this theory deals with the matter from a purely chemical point of view, and is incapable of verification by the geologist. The organic theory, however, in one or other of its branches must, from all the evidence, be held to offer in some degree an explanation of the facts at issue, as it can be tested in the light of many observed phenomena taking place up to the present time.

The decomposition of organic bodies, whether animal or vegetable, produces various forms of hydrocarbon, such as marsh or coal gas, and tar or oil, under certain conditions, as, for example, when these bodies are distilled in a retort, or when they undergo decay in the absence of air. Oily water frequently exudes from peat mosses, and marsh gas or light carbonetted hydrogen bubbles up in every stagnant pool with rotting vegetable or animal matter at the bottom. So far all observers are now agreed, and up to this stage there is no need of far-fetched chemical theories to explain what is more or less a matter of common experience. After the organic origin is granted, however, there may be some difference of view as to the way in which the decomposition has been effected.

Professor Sterry Hunt maintains that oil and gas are produced from the *primary* decomposition of organisms in the limestone or oil rock itself, while Professor J. S. Newbery holds

[1] For a full discussion of this subject, see Ed. Orton on "The Trenton Limestone as a Source of Petroleum," &c., in U.S. Geol. Survey Eighth Annual Report, pp. 487-506.

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that these products are derived from the *secondary* rather than the primary decomposition of such organisms, or that decomposition has been associated with a slow process of distillation going on continuously in the strata. Professor S. F. Peckham, again, modifies Newbery's theory of distillation in referring the operation of the process to a definite period, which has long passed away. According to this view, the distillation was caused by the heat pervading the region at the time of the elevation and metamorphism of the Appalachian Mountain system.

Of these three theories that of Sterry Hunt seems to satisfy the majority of the observed phenomena in the most natural way. Where a process can be carried out at ordinary temperatures there is not much gain in supposing high temperatures to be necessary. Had the strata been so much affected by the heat accompanying the Appalachian uplift that their hydrocarbons underwent a process of destructive distillation, as Peckham supposes, there would have been independent evidences of this metamorphic action, but all such are conspicuous by their absence in the great oil regions. In many tropical or semi-tropical areas, on the other hand, the production of solid and other hydrocarbons from decomposing vegetation is still in operation. The pitch lake of Trinidad, already referred to, derives its asphaltum from bituminous shales of late Tertiary age, whose hydrocarbons are apparently due to the direct decomposition of vegetable matter in the shales which are undergoing slow alteration at ordinary temperatures.

In connection with the discussion of the origin of oil shales, it may be noted that observation has shown that clay has a particular affinity for oily matter. Oily substances floating in muddy water have been found to attach themselves to the suspended particles of clay, and to sink to the bottom and produce a petroliferous stratum, which would ultimately become converted into bituminous or oil shale. This property seems to belong to clay in a much greater degree than to sand particles, and hence we have oil shales in abundance, while the sandstones between them have usually few traces of original bituminous matter.

The American oil sands appear, in many cases at least, to have derived their oil by a process of slow percolation from the bituminous shales below, and to have, from their porous nature, supplied reservoirs in which the oil, oozing from the shales, could accumulate in large quantities and circulate from one position to another. There may, however, have in some cases been a direct production of hydrocarbon from the decomposition of organisms in the sand-beds themselves, but it is in the associated

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shales that the great bulk of organic remains has been found, and it seems reasonable to suppose that it was the latter which formed the final resting-place of the rich flora of the period.

The occurrence of large quantities of oil and gas in the Trenton and other limestones opens up another field for discussion. In the case of the productive oil sands the porous stratum is covered by an impervious bed of shale, and when the reservoir is a limestone, it is also covered by an impervious shale bed, without which no great accumulation of oil, in America at least, can be expected. The oil found in limestone has apparently been produced in the rock by direct decomposition of organisms originally inhabiting the water in which it was deposited. Limestone oil has, however, as a rule, more sulphur and nitrogen than shale oil, and appears to be derived from animal remains, while the lighter shale oils of America seem to owe their origin chiefly to the decay of vegetation.

The limestone oils of Canada, Kentucky, Tennessee, Ohio, and California are easily distinguishable from the oils of Pennsylvania by their dark colour, higher specific gravity, and rank disagreeable odour, which diminishes their commercial value considerably.

The Lower Silurian Trenton Limestone—the valuable oil-bearing stratum of Ohio—has been found to be very porous, its porosity being almost invariably connected with its chemical constitution. It is a dolomite more or less pure wherever it contains oil and gas in any quantity, and there is evidence of a transformation of its component calcite into dolomite in the upper part of the bed at a period subsequent to its deposition. Its porosity results apparently from the highly crystalline character it has assumed during the process of dolomitisation, the spaces between the interlacing crystals forming channels for the percolation of fluids in the rock. Wherever the Trenton limestone assumes its normal character and ceases to be dolomitic, it ceases also to be markedly petroliferous in character—a fact of great importance in the search for new oil fields from this horizon.

6. Mode of Accumulation of Oil and Gas.

Having thus touched on the theory of their origin, we may next consider the way in which natural gas and petroleum have become accumulated in large quantities in certain places.

In America, what is known as the Anticlinal Theory of the distribution of oil and gas has been worked out in great detail by Professor I. C. White and others, and this hypothesis is now generally accepted as the true explanation of the phenomena observed in all the great oil fields of the world.

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Oil wells yield three products—gas, oil, and brine. In some cases only one of these is found, in others, first oil, then brine; the oil, which often comes up the hole at great pressure, being usually associated with more or less light carburetted hydrogen gas.

After much investigation it has been generally established that where the strata lie in great flat anticlines and synclines, the wells drilled along the crest of these flexures yield gas, these in the troughs give only brine, and the intermediate zone is that in which there is most probability of finding oil. The explanation is obvious; the original heavy salt water in the porous rock, when it became mixed with oily matter, derived from decomposing organisms, gradually sank to the lowest position it could reach, leaving the oil floating on its surface, while the gas, being still lighter, was forced up to the crown of the arch, where it remained under great pressure imprisoned beneath the impervious bed covering the porous reservoir.

This theory gives a general explanation of the observed phenomena, but it often occurs that there are apparent exceptions. Some wells are productive, while others near them may be "dry holes," and the explanation seems to be in the fact that although the oil is confined to particular strata or "sands," where alone it can be expected, yet these beds are not uniformly porous, and the well may strike a close-grained area through which no fluid can find its way. There may again be small local flexures, which will naturally influence the distribution of the fluids within limited areas, without affecting the validity of the general hypothesis.

To Scottish geologists, accustomed to areas where long stretches of almost undisturbed formations are practically unknown, it may seem curious that there should have been any difficulty in establishing the anticlinal theory of the occurrence of oil and gas. The American oil fields, however, occur often in regions where the rocks are very flat, the inclination being so slight that it is a matter of much difficulty to ascertain the trend of the main flexures beneath, and the surface of the country is a featureless plain deeply buried under a covering of soil and drift, and often nearly destitute of natural rock exposures. It is, no doubt, greatly due to the slight disturbance and absence of faults, that the free circulation of the imprisoned fluids is possible, and although oil might occur in sandstones in other regions, if there were many faults or evidences of disturbance such as are common here, it stands to reason that any such oil could not accumulate in quantity sufficient to afford other than a very limited supply, derived entirely from the strata in the immediate vicinity.

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7. Oil Fountains of the Caspian.

The great oil-producing region of the Old World is at Baku on the Caspian, where the industry has of late years, owing chiefly to the enterprise of the Nobel Brothers, attained to such dimensions, that the Russian oil wells are now producing nearly as much as those of the United States. The oil wells of the Caspian have been used for 2500 years, and the gas issuing from the huge naphtha deposits of that region has for long centuries kept alive the altars of the ancient fire worshippers of the East.

The oil and naphtha are here found in rocks of Eocene age, and the soil needs only to be scratched to give off its inflammable vapours. The Baku wells are not nearly so deep as those of America, as fountains of petroleum are usually struck at depths of less than 1000 feet, while the American wells are frequently drilled to depths of 2000 feet or more before the oil is reached. At Baku, again, the oil seems to lie in great cavities, due perhaps to the subsequent folding or faulting of an older set of anticlinal oil sands, so that one productive well may often be sunk close to another without affecting its production. In the States spouting wells are common enough where the fluid ascends under great pressure, and if the hole be not securely plugged up, rises high into the air in a lofty fountain, one of which I was fortunate enough to see in 1891, near the township of M'Donald. In this case, on the "cap" being removed, the oil spouted high into the air.

The spouting wells of the Caspian, however, far outstrip their American competitors in volume and energy. Mr Charles Marvin, in his fascinating book, the "Region of the Eternal Fire," gives graphic accounts of these marvellous eruptions, from which the following examples are taken.

The first oil fountain on the Caspian occurred in 1873, when a reservoir of oil was suddenly struck by the boring tool. The fluid rose 40 feet into the air, and the flow was so great that the price of crude petroleum fell from 45 to 5 copeks the pood, or about from 2½d. to ¼d. per gallon, since which it has never risen above ½d. per gallon.

In 1875 a third fountain was tapped, which spouted 600,000 gallons of oil every 24 hours, and other eruptions, more or less violent, occurred shortly afterwards in the district, from which such floods of oil were ejected as to defy collection and form lakes of oil in the vicinity, some of which are still in existence, and others have been burnt off to clear the ground.

Another great fountain occurred in 1883. A 12-inch tube

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was employed, and at a depth of 420 feet there was a terrific outburst of gas, which was repeated at a depth of 490 feet. At 546 feet there was a third explosion, which hurled the pumping cylinder into the air and smashed the top of the derrick to pieces. A jet of dry sand and grit began to spout into the air to a height of nearly 400 feet. This sand volcano lasted for 45 minutes, and was followed by a furious blast of gas which poisoned the atmosphere at Balakhani for the rest of the day. A cap was, after much trouble, fixed on the hole so as to stop the flow of oil which came afterwards, and as there was then no demand for petroleum, the well was stopped until required.

The great fountain of 1883—the Droojba—exceeded in magnificence anything that had hitherto been heard of, and its fame spread into every part of Europe. The depth of this well was 574 feet, and during the first four months the quantity of oil that burst forth like a mighty geyser was reckoned at 220,000 tons, or about 55,000,000 gallons, the vast majority of which, for want of adequate storage accommodation, flooded the surrounding country, and then ran off in a broad stream into the Caspian, where it was utterly lost. Sand and stones were hurled high into the air, and the top of the derrick, which was 70 feet high, was blown off with the first eruption, after which the column of oil and sand shot upwards to heights of 200 to 300 feet, rising or falling according as the 10-inch orifice of the well was open or temporarily choked with occasional pieces of stone. The remarkable feature of this well was, that instead of making its owner a millionaire, as would have been the case in America, it both ruined him and broke the heart of the engineer who bored it. The reason was that the fountain belonged to a small Armenian company, which had enough ground for a well, but not enough for large reservoirs. The oil flowed over neighbouring properties, and was partially caught and sold by those on whose land it trespassed, and the quantity was so great as to reduce the price enormously, while at the same time the deluge of sand did so much damage in swamping the neighbouring wells and houses, that the amount of compensation claimed from the Droojba company far exceeded the value of the oil recovered by them.

Up till 1883 the Droojba, which spouted 3400 tons of oil a day,—nearly as much as the 25,000 wells of America put together,—had been looked on as a phenomenon the like of which would never be heard of again. It was, however, surpassed by the Tagieff eruption in 1886, which, for a few days, belched forth, from a 10-inch orifice, in one stupendous column, no less than 11,000 tons, or about 2¾ million gallons, of petro-

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leum per diem. This well, belonging to Gospodin Tagieff, was situated on the promontory of Bybyibat three miles south of Baku, and was commenced in 1884 in a hitherto comparatively unproductive district. At its best it had not at first yielded more than 16,000 gallons a day—a production insufficient to excite competition at Baku. As the production diminished it was deepened to 714 feet, when the main reservoir was suddenly tapped, and the oil burst forth with terrific violence. The eruption covered hill and dale with sand and oil, and nothing could be done to stop the flow. The petroleum filled up the hollows, formed a lake, and on the fifth day began pouring into the sea at the rate of 5000 or 6000 tons daily. On the sixth day the wind freshened, and the oil fell in showers on the houses of Baku, three miles away, and the maximum of $2\frac{3}{4}$ million gallons a day was reached on the eighth day, after which the flow began to abate. By the fifteenth day the pressure had so far diminished as to allow of the outflow being controlled to a quarter of a million gallons by the engineers in charge, but not before nearly 10 million gallons had been lost for want of adequate storage at the well.

Still greater fountains have been struck within the last two years, one of which, at a depth of 1100 feet, started off with 100,000 barrels, or about 16,000 tons a day. In March 1892, several large fountains on the Apsheron Peninsula produced at first no less than 2,000,000 poods, or 32,258 tons, a day for a short time.[1]

8. Natural Gas: Its Composition.

Every oil well contains more or less "Natural Gas" of an inflammable character associated with the petroleum. But in oil regions gas wells without oil are, as has been already stated, found by boring along the crest lines of anticlinal flexures. This substance is not a definite chemical compound, but a mixture of gases, the principal constituent being Marsh Gas or Light Carburetted Hydrogen (CH_4), with usually some free Hydrogen, Ethyl Hydride (C_2H_6), Olefiant Gas (C_2H_4), Oxygen, Nitrogen, Carbonic Oxide (CO) and Carbonic Acid (CO_2). The relative proportions of these constituents are very variable, and sometimes they are not all present, or there may be in addition small quantities of other gases, such as Sulphuretted Hydrogen H_2S. An analysis of the Findlay Gas from the Trenton Limestone, made in 1885, by Professor C. C. Howard, of Starling

[1] Consular Report for 1892 on Trade of Batoum, No. 1191, and *American Manufacturer*, 2nd February 1894.

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Medical College, Columbus, for the Ohio Geological Survey, gave the following results :—[1]

Marsh Gas (CH_4)	92·61
Olefiant Gas (C_2H_4)	0·30
Hydrogen	2·18
Nitrogen	3·65
Oxygen	0·34
Carbonic Acid	0·26
Carbonic Oxide	0·50
Sulphuretted Hydrogen (H_2S)	0·20
	100·04

The percentage of Marsh Gas is often much lower than this, although in some cases it rises to 94% in the Findlay Gas district. The composition of the gas in the same well has also been found to vary from time to time, as the following analyses will show. These analyses were taken from one well on 18th, 25th, 28th, 29th October, and 4th December 1884, and are quoted at p. 23 of Mr Chas. A. Ashburner's paper on "Natural Gas," read before the American Institute of Mining Engineers, October 1886 :—

		(*a.*)	(*b.*)	(*c.*)	(*d.*)	(*e.*)	(*f.*)
Marsh Gas,	CH_4	57·85	75·16	72·18	65·25	60·70	49·58
Hydrogen,	H	9·64	14·45	20·02	26·16	29·03	35·92
Ethylic Hydride,	C_2H_6	5·20	4·80	3·60	5·50	7·92	12·30
Olefiant Gas,	C_2H_4	0·80	0·60	0·70	0·80	0·98	0·60
Oxygen,	O	2·10	1·20	1·10	0·80	0·78	0·80
Carbonic Oxide,	CO	1·00	0·30	1·00	0·80	0·58	0·40
Carbonic Acid,	CO_2	0·00	0·30	0·80	0·60	0·00	0·40
Nitrogen,	N	23·41	2·89	0·00	0·00	0·00	0·00
		100·00	99·70	99·40	99·91	99·99	100·00

The variations in this table are remarkable, especially in the column (*a*) where the enormous quantity of Nitrogen indicates a different source of the gas on the day the sample was taken, and perhaps also the admixture of more air than usual with the gas.

9. Pressure of Natural Gas.

The extraordinary pressure which the gas exerts in most wells is a subject of much interest, both scientific and economic, as it is this condition which enables the gas to be conveyed long distances, and used in immense quantities for lighting and

[1] Orton, *Trenton Limestone, loc. cit.*, p. 591.

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heating cities often many miles from the source of supply. The following examples, taken from Peckham's report (p. 243), provide much interesting material for reflection.

In some instances the gas, which has been securely retained, has been conveyed in pipes to the cylinder of a steam engine, and employed directly to drive the engine as if it were high pressed steam. This was done at the Roy Well, near Kane, Pennsylvania, where the engine was more than a quarter of a mile off. Sometimes a well has been drilled through a watery stratum or feeder before reaching the gas, and the struggle between the two elements in their haste to escape has produced a splendid display, the water being shot up in huge jets at regular intervals like a geyser. In a well of this kind near Gambier, Knox County, Ohio, the water round the hole became frozen into a solid pipe, and the gas could be safely ignited without danger to the derrick, which was covered with ice. The effect, especially at night, of the mingled column of water and fire leaping up in fierce roaring paroxysms to a height of 120 feet, through a transparent illuminated chimney, is said to have been indescribably magnificent.[1] This freezing up of the well brings to notice another phenomenon sometimes observed in gas wells. The sudden expansion of a large volume of imprisoned gas naturally causes a great fall in its temperature at the orifice of the well. Cases have been recorded where the cold became so great that the ice which formed in the pipe completely closed it. This occurred at Sheffield, where, after the well was thus choked, the ice had to be drilled to a depth of 100 feet before it was reopened. When it was pierced the pressure was so great that the tools and casing were shot out through the top of the derrick.

The amount of pressure in gas wells has often been measured. It frequently reaches 500 lbs. per square inch, and sometimes rises to 700, 800, or even 1000 lbs. In the spouting oil well, which I was fortunate enough to see near M'Donald township, Pennsylvania, the pressure was so great that when the "cap" was removed the heavy boring-tool, 8 inches in diameter and about 30 feet long, was shot upwards a short distance, and was followed by a mingled jet of gas and oil, which mounted 100 feet into the air. The roar of a high-pressure gas well when the orifice is open is perfectly deafening, and if the gas is ignited its flare can sometimes be seen 40 miles away. In the Ohio district, which I visited in 1891, the whole locality was lit up at night with blazing jets of gas, and so plentiful was the supply, that at many places it was

[1] Peckham, *loc. cit.* quoting Prospectus of the Neff Petroleum Company, 1866.

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not thought worth while to conserve or turn off the gas during the day, the greater part of which was allowed recklessly to go to waste in the atmosphere.

The cause of the enormous pressure of natural gas is to be explained in two ways. The theory which meets most of the facts is a simple one, but is not, I think, of altogether universal application. According to this hypothesis, the pressure in gas wells is due to the same cause as the pressure in the gas mains of a town, viz., the column of water behind it.[1]

The oil and gas sands are full of brine, whose hydrostatic pressure is proportional to the depth of the well or the height of the column in the strata from the surface-level downwards. A column of pure water 20 feet high produces a pressure of 9 lbs. per square inch, and a column 1000 feet high will, in the same proportion, exert a pressure of 450 lbs. While if the water contains salts, its increased weight will make the pressure still greater. When gas is struck at a depth of 1000 feet, therefore, if there is, as there must be, according to the anticlinal theory, a porous stratum permitting tolerably free circulation of fluids, the pressure at the bottom of the hole may at first, at all events, be naturally expected to reach 450 lbs. or more, which will, of course, be also the pressure, or nearly so, of the gas at the orifice of the well. In the case of a spouting oil well the pressure cannot be so great, as the oil, although lighter than water, is much heavier than gas, and the pressure required to eject the oil is that due to the difference in weight of the two columns. Petroleum, however, in such cases usually comes up largely mixed with gas, so that in reality the oil in the pipe is much lighter than when in its normal state, and hence the pressure exerted is higher than that theoretically due to the difference just stated. In the case of the great Droojba fountain at Baku, the pressure is stated to have exceeded 13 atmospheres, or about 190 lbs. per square inch, and the depth of the well was 574 feet.[2] If the first of these figures be correct, and there were no gas mixed with the oil, it is difficult on this theory to explain the force of the outburst. Roughly speaking, a column of oil with sp. gr. 0·8 is $\frac{1}{5}$ lighter than an equal column of water, so that the difference of pressure at a depth of 574 feet would be equal to a column of water $\frac{1}{5}$ of 574=125 feet high, or about 54 lbs. per square inch instead of 190 lbs. If this theory is applicable here the brine behind the oil must have been very heavy indeed, and the oil must have been reduced in specific

[1] See Orton on the Trenton Limestone, *loc. cit.*, p. 593.
[2] Marvin, "Region of the Eternal Fire," p. 229. (1891 ed.)

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gravity by mixture with several times its bulk of gas. On the other hand, it was often heavily charged with stones and sand; and although there was some gas present, yet it is difficult to see how the ascending column could have been rendered light enough to burst forth and produce such a deluge of oil by hydrostatic pressure alone.

Another phenomenon, known as a "gas volcano," has been observed in America, which seems inexplicable by the hydrostatic pressure theory alone. In the valley of the Cumberland, near Burkesville, in Southern Kentucky, frequent cases have been observed,[1] where the pressure of the imprisoned gas, apparently being generated beneath impervious strata, has so increased as to overcome the superincumbent weight from time to time, and throw off the overlying rock, earth, and water, in the explosion. These considerations lend weight to the second theory that the gas in some cases produces its own pressure during the change in volume, when passing from the solid state, in which its constituents were originally present in the strata, to its ultimate gaseous condition. Anyone who has been down a fiery coal pit cannot fail to have noticed the pressure at which the gas comes hissing from the "working faces" of the coal, and in this case there is no hydrostatic pressure behind it. As a rule, however, I think that the first theory explains more or less adequately the uniform pressure observed over a gas field in different wells, and that the second theory is only applicable in a limited number of cases, and may help to explain the initial abnormally high pressure, such as has been observed at Baku and elsewhere, which has produced explosions, the effect of which, although tremendous at first, has not been of long duration. According to the hydrostatic hypothesis, again, the greater the depth of the well the greater will be the pressure of the gas, and this has, as a general rule, been fully borne out by observation. There can, therefore, on the whole be no great difficulty in accepting this as a sufficient explanation of the phenomenon of pressure observed in the most important fields of natural gas and oil.

10. Production of Petroleum in America.

A few words on the economic aspects of the natural gas question may form a fitting conclusion to these observations. The question is often asked, How long are these supplies of fuel to last? From what has been said, the answer must be obvious. The same answer is given to the question of the durability of

[1] Peckham's Report, p. 243.

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our coal fields. The natural supply of fluid hydrocarbons, as of coal, is limited, and will never be increased; and further, the age of a productive oil well does not generally exceed five years in America, and is very often much less. A spouting oil well does not continue to gush forth for many weeks if allowed to flow freely. It soon degenerates into a flowing well and then into a pumping well, whose production dwindles away and finally ceases to be remunerative, so that, unless new wells are continually being discovered, the output must fall off and then cease entirely.

The vast supplies of natural gas, for example, in the vicinity of Pittsburg, which for some years lighted the city and superseded coal in its ironworks and manufactories, are now beginning to give out. When the gas was introduced the murky pall of smoke that formerly covered the town was banished, and the air became clear and wholesome, but now the visitor notices the return of the smoke, and in a few years the atmosphere may return to its old condition. The skill which has been expended in the development of the oil and gas wells of the States, and the conveyance of these precious products through many hundreds of miles of pipe-lines from the source to the market, has been marvellous, and will ever form a monument to the inventive genius of the Americans. It is only equalled by the skill and perseverance of our own oil manufacturers in Scotland, who have, in the face of crushing competition from more favoured lands, been able to produce mineral oil and its accessories by distillation from the native shale, and to keep their works afloat under difficulties sufficient to appal the stoutest heart, and which, but for the *perfervidum ingenium Scotorum*, would long ago have put an end to all our oilworks,—a fate which has, indeed, already overtaken several of them.

It was the success of Mr Binney and Mr James Young in distilling oil from the Boghead Cannel in the early fifties that really started the modern oil industry both here and in America. The first mineral oil produced in the United States was by distillation from coal tar mixed with cheap animal and vegetable oils, and subsequently from Albert coal or Albertite, a kind of asphaltum obtained from New Brunswick, and bituminous coal and shale from many other places. Experiments in this process were carried on by Messrs Luther and William Atwood, near Boston, in 1850-1, and by Mr Joshua Merrill, who joined them in 1854, and these three men were the pioneers in the manufacture of American paraffin oil. Boghead Cannel was imported in 1859, and distilled in some works, while the rich Cannel coals of West Virginia and Kentucky were treated similarly in others.

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The year 1859 marks the starting point of the new American oil industry. For some years previously attention had been turned to the oil oozing out of the ground at certain places, and attempts had been made to collect and use it commercially. But the first really important oil well was that sunk at Titusville, Pennsylvania, by Mr E. L. Drake, who drilled a hole 33 feet deep, on 28th August 1859, when the tool dropped 6 inches into a crevice, and next day found the hole nearly full of petroleum. Henceforward drilling began over a wide district, and many flowing wells were found. In June 1860 the total daily product of all the wells was about 200 barrels. By September 1861 this had reached 700 barrels when the flowing well period began, adding to the production 6000 or 7000 barrels a day. The price of oil fell to 20, 15, and 10 cents. a barrel (of 42 gallons capacity), which so disheartened the operators that many of them gave up in despair, and the production languished for some years. It did not at first increase very rapidly, but after 1865 a steady improvement began, and the subsequent history of the production is related *in a line* on the accompanying diagram (plate II.), constructed from the table on the following page, taken from Mr Joseph D. Weeks' Report on Petroleum in 1893,[1] a copy of which the author has kindly sent me. The average prices for the same period are also shown graphically in a dotted line. From this table it will be observed that up till 1876 nearly all the American petroleum was obtained from the States of Pennsylvania and New York. In 1885, after the discovery of oil in the Trenton Limestone, the Ohio and West Virginian oil fields began to pour in their increased quota, and about the same time the Californian Miocene oil supplies grew in importance, and shortly afterwards Colorado and Indiana were added to the list of petroliferous states. The production of American petroleum reached its zenith in 1891, and the two following years show a marked decline in the older fields of New York and Pennsylvania, whose production has fallen from 33 to 20 million barrels during this period. The approaching exhaustion of the Eastern oil fields is being partially compensated for by the growth of the West Virginia and Indiana oil regions, but the net result is a decrease of about 6 million barrels since 1891, so that unless new fields are opened up soon, the production of American petroleum is not likely to increase very much in the near future. Prices reached low water mark in 1892, and started to move upwards last year as the supplies began to diminish.

[1] "Mineral Resources of the United States." Washington, 1894.

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Production of Crude Petroleum in the United States from 1859 *to* 1893.

[Barrels.]

Year.	Pennsylvania and New York.	Ohio.	West Virginia.	Colorado.	California.	Indiana.	Kentucky and Tennessee.	Illinois.	Kansas.	Texas.	Missouri.	Indian Territory.	Total United States.	Average Yearly Prices per Barrel.
1859	2,000	...	...	...	...	...	...	...	...	...	...	...	2,000	...
1860	500,000	...	...	...	...	...	...	...	...	...	...	...	500,000	$9.59
1861	2,113,609	...	...	...	...	...	...	...	...	...	...	...	2,113,609	0.49
1862	3,056,690	...	...	...	...	...	...	...	...	...	...	...	a3,056,690	1.05
1863	2,611,309	...	...	...	...	..	...	...	...	...	...	...	2,611,309	3.15
1864	2,116,109	...	...	...	...	...	...	...	...	...	...	...	2,116,109	8.06
1865	2,497,700	...	...	...	...	...	...	...	...	...	...	...	2,497,700	6.59
1866	3,597,700	...	...	...	...	...	...	...	...	...	...	...	3,597,700	3.74
1867	3,347,300	...	...	...	...	...	...	...	...	...	...	...	3,347,300	2.41
1868	3,646,117	...	...	...	...	...	...	...	...	...	...	...	3,646,117	3.62½
1869	4,215,000	...	...	...	...	...	...	...	...	...	...	...	4,215,000	5.63½
1870	5,260,745	...	...	...	...	...	...	...	...	...	...	...	5,260,745	3.84
1871	5,205,234	...	...	...	...	...	...	...	...	...	...	...	5,205,234	4.34
1872	6,293,194	...	...	...	...	...	...	...	...	...	...	...	6,293,194	3.63
1873	9,893,786	...	...	...	...	...	...	...	...	...	...	...	9,893,786	1.87
1874	10,926,945	...	...	...	...	...	...	...	...	...	...	...	10,926,945	1.15
1875	8,787,514	b200,000	b3,000,000	...	b175,000	...	...	...	...	...	...	...	b12,162,514	1.36
1876	8,968,916	31,763	120,000	...	12,000	...	...	...	...	...	...	...	9,132,669	2.56½
1877	13,135,475	29,888	172,000	...	13,000	...	...	...	...	...	...	...	13,350,363	2.42
1878	15,163,462	38,179	180,000	...	15,227	...	...	...	...	...	...	...	15,396,868	1.19
1879	19,685,176	29,112	180,000	...	19,858	...	...	...	...	...	...	...	19,914,146	0.85½
1880	26,027,631	38,940	179,000	...	40,552	...	...	...	...	...	...	...	26,286,123	0.94½
1881	27,376,509	33,567	151,000	...	99,862	...	...	...	...	...	...	...	27,661,288	0.85½
1882	30,053,500	39,761	128,000	...	128,636	...	c160,933	...	...	...	...	...	30,510,830	0.78½
1883	23,128,359	47,632	126,000	...	142,857	...	4,755	...	...	...	...	...	23,449,633	1.05½
1884	23,772,209	90,081	90,000	...	262,000	...	4,148	...	...	...	...	...	24,218,438	0.83½
1885	20,776,041	650,000	91,000	..	325,000	...	5,164	...	...	...	...	...	21,847,205	0.87½
1886	25,798,000	1,782,870	102,000	...	377,145	...	4,726	...	...	...	...	...	28,064,841	0.71½
1887	22,356,193	5,018,015	145,000	76,295	678,572	...	4,791	...	...	...	...	...	28,278,866	0.66½
1888	16,488,868	10,010,868	119,448	297,612	690,833	...	5,096	...	...	...	...	...	27,612,025	0.87½
1889	21,487,435	12,471,466	544,113	316,476	303,200	33,375	5,400	1,460	500	48	20	...	35,163,513	0.94½
1890	28,458,208	16,124,656	492,578	368,842	307,360	63,496	6,000	...	1,200	54	278	...	45,822,672	0.86½
1891	33,009,736	17,740,301	2,406,218	665,482	323,600	136,634	9,000	...	1,400	54	25	30	54,291,980	0.67
1892	28,422,377	16,362,921	3,810,086	824,000	385,049	698,068	6,500	...	...	45	10	80	50,509,136	0.55½
1893	20,314,513	16,249,769	8,445,412	594,390	470,179	2,335,293	3,000	...	...	50	50	10	48,412,666	0.64
Total...	478,492,880	96,990,189	20,481,855	3,143,097	4,769,450	3,266,866	219,513	1,460	3,100	251	383	120	607,369,164	

a In addition to this amount, it is estimated that for want of a market some 10,000,000 barrels ran to waste in and prior to 1862 from the Pennsylvania fields; also a large amount from West Virginia and Tennessee.

b Including all production prior to 1876 in Ohio, West Virginia, and California.

c This includes all the petroleum produced in Kentucky and Tennessee prior to 1883.

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11. The Russian Oil Industry.

While the production of American petroleum has thus at present apparently reached high-water mark, the output from the Caspian wells is steadily rising, and these bid fair very soon to outstrip their Western competitors, and supply the Old World with most of its liquid fuel and kerosene. From 1877, when the Nobels began operations at Baku on intelligent modern principles, such as had been adopted in America, and the Russian Government removed all taxes and restrictions, the oil industry sprang up and developed at a marvellous rate. Up till 1871 the oil wells were sunk as *pits*, of which, in 1872, there were 415. In 1871 the first well was *drilled* on the American system, and henceforward this system came into use all over the oil district. The number of drilled wells in 1872 was 2, in 1874 50, in 1876 101, in 1879 301. At the end of 1893 324 wells were producing oil over a district not exceeding 3000 acres in extent, 46 old wells were being cleaned out and repaired for work, and 59 new wells were being drilled. The new wells are often deeper, as has been already mentioned, than those of the last decade, but there is no sign as yet of general exhaustion of this wonderful oil field, and the fact has been referred to above that in March 1892 the production of the wells on the Apsheron peninsula reached for some time the vast total of 32,258 tons of oil per diem when several large fountains were first struck. In November 1893 a well was struck at a depth of 109 feet, which at first yielded 100,000 barrels, or over 16,000 tons per diem, but soon settled down to less than a fifth of that production. Another fountain, struck at 1100 feet, as already mentioned, started off at the same rate of flow, which it maintained for some days.

Although by far the largest production of Caspian oil is as yet derived from the Apsheron peninsula, recent explorations have proved oil to exist in great abundance at Grosni on the Vladikavkaz railway, and it is reported that this district bids fair, when adequately developed, to become a very formidable competitor to Baku.

The figures given in the following table are taken from different sources, and it is to be noted that the totals are only approximate, as the returns obtained by different authorities vary very considerably owing to the difficulty of getting accurate reports on the ground. From 1863 to 1886 inclusive my authority is Marvins' "Region of the Eternal Fire" (1891 edition). For 1887 the British Ambassador at St Petersburg is the source, and from 1888 to 1893 the figures are obtained from the British Consular Reports on the Trade of Batoum. The

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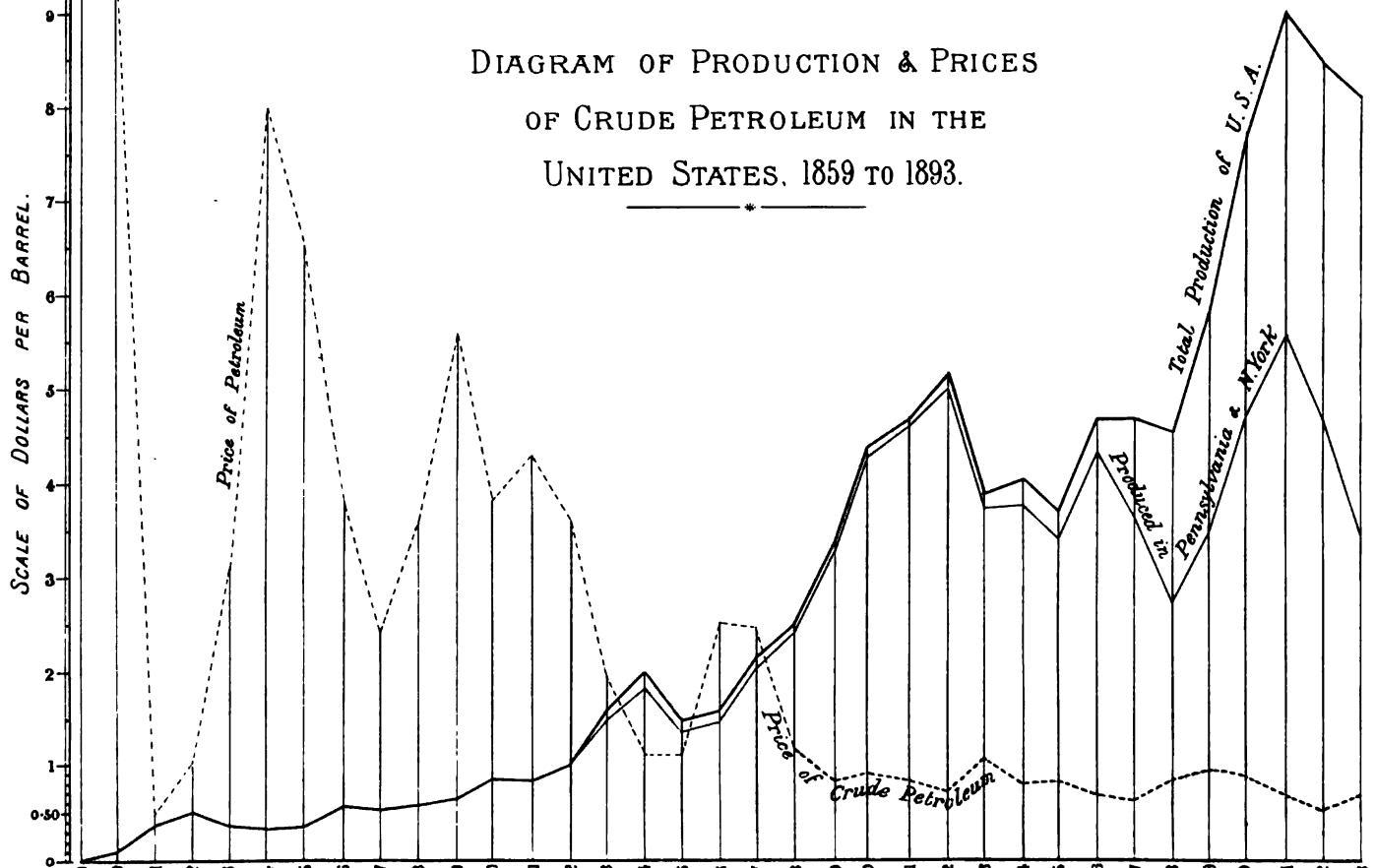
Trans. Geol. Soc. Edin.r, 1894, Vol. VII, Pl. II.

H. M. C. del.t

DIAGRAM OF PRODUCTION & PRICES OF CRUDE PETROLEUM IN THE UNITED STATES, 1859 TO 1893.



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returns for the last five years are from the 1894 Report, which, it may be mentioned, differ slightly from the figures given in the individual reports for these years. For purposes of comparison with the American returns, I have given the production both in tons and in American barrels, 7 barrels being taken as equal to 1 ton. As the Russian production is often given in poods (pouds or puds), it may be mentioned that 1 pood= 36·112 British pounds, or about 4 gallons, 62 poods being= about 1 ton of oil. An American barrel of 42 Winchester gallons contains only 35 imperial gallons, and, assuming that Russian oil has an average specific gravity of 0·875, an American barrel contains 10·18 poods.

PRODUCTION OF CRUDE PETROLEUM AT BAKU

(in tons and American 42-gallon barrels).

	Tons.	Barrels.		Tons.	Barrels.
1863	5,484	38,388	1879	370,000	2,590,000
1864	8,700	60,900	1880	420,000	2,940,000
1865	8,900	62,300	1881	490,000	3,430,000
1866	11,100	77,700	1882	680,000	4,760,000
1867	16,100	112,780	1883	800,000	5,600,000
1868	11,900	83,300	1884	1,435,000	10,045,000
1869	27,180	190,260	1885	1,780,000	12,460,000
1870	27,500	192,500	1886	2,000,000	14,000,000
1871	22,200	155,400	1887	2,116,000	14,812,000
1872	24,800	173,600	1888	2,580,000	18,060,000
1873	64,000	448,000	1889	3,315,203	23,206,421
1874	78,000	546,000	1890	3,857,335	26,201,345
1875	94,000	658,000	1891	4,657,506	32,602,542
1876	194,000	1,358,000	1892	4,621,107	32,347,749
1877	242,000	1,694,000	1893	5,436,318	38,054,226
1878	320,000	2,240,000			

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X.—*Obituary Notice of William Pengelly, F.R.S., Associate.*

By RALPH RICHARDSON, F.R.S.E.

(Read 3rd May 1894.)

WHEN I read, three months ago, my paper on Kent's Cavern, I little thought I should so soon have to chronicle the death of its famous explorer, William Pengelly. That sad event occurred at Torquay on 17th March last.

The son of a Cornish fisherman, William Pengelly was born at East Looe, a village in Cornwall, on 12th January 1812, so that he died at the ripe age of eighty-two. He began life as a sailor, but his scientific leanings made him become a teacher at Torquay, where he established a school. To the end of his life he continued giving lectures on Science at schools and institutes, possessing, as he did, in a rare degree, the art of presenting Science to the public in a lucid and attractive way. But he was not merely an admirable speaker, he was also a man of action. He established the Torquay Mechanics' Institute in 1837. He founded the Torquay Natural History Society in 1844, and the Devonshire Association in 1862.

It was in 1841, when twenty-nine years old, that Pengelly attended the sale of the effects of the Rev. John MacEnery, who had just died. MacEnery had from the year 1825 made continuous researches into a then little known cave near Torquay, popularly called "Kent's Hole." Himself a Roman Catholic priest, MacEnery called in the assistance of an eminent Anglican clergyman, the Rev. Dr Buckland, author of "Reliquiae Diluvianae," who was at that time the great authority on ossiferous caves in Britain, and together they investigated Kent's Cavern.

At the sale of MacEnery's effects, Pengelly observed that a Torquay tradesman bought for a small sum "an old tea-chest filled with papers and odds and ends, including splinters of bones." These are Pengelly's own words in his address to the Royal Cornwall Polytechnic Society in 1886. He continues:—"A few years afterwards, Professor Owen and others, having in the interval deplored the loss of the manuscripts, he (the tradesman) turned out the contents of the tea-chest, and there were the missing papers. They were ultimately presented to the Torquay Natural History Society. In 1869 I transcribed the whole, and gave it to the world as MacEnery left it."

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Simple as this narrative is, it contains the germ of the life-work of William Pengelly. The contents of that tea-chest set him thinking, and led him to devote to the systematic examination of Kent's Cavern the remainder of his long and busy life. In 1846 the Torquay Natural History Society appointed a committee of three, of whom Pengelly was one, to make some researches in the cave, for the purpose of getting specimens for the Society's museum. They found what Northmore, MacEnery, Buckland, and Godwin Austen had already found there, "remains of extinct animals in the Cave-earth, and with them flint implements."

Another and similar cavern was discovered by Philp in 1857 at Brixham, on the southern shore of Torbay. Pengelly visited and investigated it, and read a paper on the subject before the British Association at Leeds in 1858. The discoveries in that cave, says Pengelly, "revolutionised the opinions then held on the antiquity of Man. Falconer, Lyell, Prestwich, Ramsay, and others, gave in their adhesion to the opinion that Man was indeed an occupant of Devonshire in times far earlier than our fathers had supposed."

It was in 1864, however, when the British Association met at Bath, that the most thorough and systematic exploration of Kent's Cavern was resolved on. A committee was appointed, with Pengelly as secretary, and a grant of money was given. The work thus begun in 1864 was not ended until 1880. For fifteen years and three months Pengelly laboured at the investigation of Kent's Cavern. He went to it, he says, every day of his life from the 28th March 1865 to 19th June 1880, when the work was brought to a close. The result of the labours of the committee will be found in the Reports printed by the British Association. Never was cave so thoroughly investigated; and for this constant and conscientious labour of years, and for the invaluable contributions thus made to our knowledge of the antiquity and surroundings of primeval Man, the world is indebted to William Pengelly.

Pengelly was elected an Associate of the Edinburgh Geological Society in 1888, and contributed two papers to the Society's "Transactions." The first of these, read on 19th January 1888, and published in Vol. v. p. 507. described some recent discoveries in Bench Cavern, Brixham, Devon; and the second, read on 18th April 1889, and published at p. 37, Vol. vi., is entitled "An Old Man and Woman; or, Human Bones in a Scrobicularia Bed at Newton Abbot, Devonshire."

Of course Pengelly was the recipient of endless praise and distinguished honours. Members of the British Association and other societies presented him with a testimonial of the value of

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500 guineas in 1874, whilst his portrait (which he at once presented to the Torquay Natural History Society) was painted by subscription in 1881. In October 1890, after holding it for thirty-nine years, he retired from the office of hon. secretary of the Torquay Natural History Society, and he then received an illuminated address attesting the high respect in which he was held. The language of the President (Mr Karkeek) of that Society, when he referred to Pengelly at the first meeting occurring after his death, may, as coming from one who knew him well, fitly close this brief Obituary notice:—"If there was one distinctive trait which specially marked Pengelly out among his fellow-men, it was his thoroughness in everything he undertook. Whether as a citizen, as a professional man, as a scientist, or as a friend, he invariably went straight forward according to his lights. As a citizen he performed his duties, and often, indeed, more, and this to his own disadvantage sometimes; as a professional man, he was most conscientious and painstaking; and as a scientist, he was accuracy itself. When William Pengelly reported an observation, although some might differ from the conclusions he drew therefrom, the observation itself was beyond dispute; it was indeed *a fact*. Lastly, as a friend, he was the personification of fidelity, integrity, and generosity."

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XI.—*Note on Croll's Glacial Theory.* By Prof. W. M. DAVIS, Harvard College, Cambridge, Mass., U.S.A., *Foreign Corresponding Fellow.*

(Read 3rd May 1894.)

THE recent studies of Dr Julius Hann of Vienna, on the origin of cyclones and anticyclones, suggest an amendment to Croll's physical explanation of the climate of the glacial period, to which I desire to ask the attention of the Geological Society of Edinburgh.

In the first place, there appear to be three classes of facts calling for a common explanation; the extension of glaciers from various centres of snow accumulation; the extension of lakes in various interior basins; and the extension of rainfall over the now dry northern border of the Sahara. It is not yet directly demonstrated that all these extensions were synchronous; but they appear to have been so, as far as evidence now in hand can decide the case. In another respect, however, they are closely associated; this is in their all being winter products; indeed, they may all be regarded as the products of more wintry winters than we now have. Where snowfall is now heavy, more snowfall would produce glaciers; where interior basins are now arid, they are less parched under the winter storms than under the summer sun; where the northern Sahara is now dry and dusty in summer, it has some rainfall in winter, but not so much as formerly.

Croll's theory attempted to account for the first of these effects of more severe winters by his well-known astronomical theory; but he gave little attention to the processes by which snowy precipitation would be produced, and he had little to say about the other series of facts which may be reasonably associated with the former extension of glaciers and ice sheets. It seems, however, that all three series of facts follow closely from the conditions argued by Croll, and it is to the meteorological processes involved in their explanation that I will now turn.

Croll argued in favour of long and cold aphelion winters as the chief cause of the glacial period. In such winters, the rate of decrease of temperature from equator to pole would be rapid; the differences of atmospheric pressure thus determined would be strong, and the general circulation of the atmosphere in the winter hemisphere would be accelerated. It is well known

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that under existing conditions the winds of the winter hemisphere are stronger than those of the summer hemisphere. The difference in their strength would have been still greater during the conditions inferred by Croll as accounting for the glacial period. It is to the increased strength of the winds in the winter hemisphere, that I believe we may look for an effective cause of the several classes of facts already enumerated.

In the first place, consider the effect of a more active general circulation on the production of precipitation. Dr Hann's discussions of the meteorological observations on the Sonnblick, the highest meteorological station of Europe, and of other Alpine stations, has led many to reconsider their former belief in the convectional origin of cyclones and anticyclones; those great travelling areas of whirling winds with centres of low or high pressure, by which the temperate zones are so strikingly characterised. There has been a general acceptance, provisionally at least, of Dr Hann's explanation of the dynamic origin of cyclones and anticyclones, as driven eddies in the somewhat tangled movement of the general circumpolar winds. The occurrence of more and stronger cyclonic and anticyclonic disturbances in winter than in summer favors this view. If convectional, the disturbances should have their maximum of frequency and intensity in summer, when the vertical temperature gradient is strongest, and when the absolute humidity of the air affords the greatest assistance to convectional movements by the more plentiful supply of latent heat liberated in the condensation of cyclonic clouds. If dependent on the strength of the general circumpolar winds, it is natural that the disturbances should be stronger in winter, when the general circulation is strengthened by the increased difference of equatorial and polar temperature then prevailing.

A longer and more severe winter would therefore provoke more active cyclonic processes, and it is entirely upon these that our snowfall in temperate latitudes depends. It is not correct to urge, as some geologists have done, that the snowfall for a glacial period requires an increased amount of vapor in the atmosphere, and hence a higher temperature. The essential thing is to cause a greater precipitation of snow, and this requires a greater activity of winter cyclonic storms, and a longer duration of the winter in which they occur. The local convectional rainfall of the doldrums, the violent intertropical cyclones of the autumnal season, and the active thunderstorms of heated land areas, all flourish in times and regions of strong sunshine, strong vertical temperature gradients, high humidity, and active convectional overturnings; but temperate and higher

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latitudes receive practically no snowfall from them. Snowfall depends on winter storms; these in turn would seem to depend on the general winds; these on the increased contrast of equatorial and polar temperatures; and this on the long aphelion winter.

In the second place, the cyclonic storms that produce snowfall in higher latitudes, produce rainfall in middle latitudes. The conditions which would cause an accumulation of snowfall in north-eastern America from the cyclonic storms of winter, would also cause an accumulation of rainfall in the interior basins of Utah and Nevada. The same common process would cause an expansion of snowfields in north-western Europe, and an extension of lakes in the arid regions of south-western Asia.

In the third place, an increased severity of winter temperatures would carry the belt of winter rains further south over the northern Sahara. This requires a little explanation. The rainfall of the northern Sahara belongs to the class known as sub-tropical rainfall. It occurs in winter, when the tropical belt of high pressure moves towards the equator, allowing the prevailing westerly winds, with their cyclones and anticyclones, to encroach on a belt of country that was six months before swept over by the parching trade winds. Now let it be remembered, that the tropical belt of high pressure owes its existence to the whirl of the general atmospheric circulation around the pole; and further, that this belt of high pressure migrates with the seasons, being pushed towards the equator in winter, when the general circumpolar winds are stronger, and relaxing towards the pole in summer, when the circumpolar winds are weaker. From this it is plain that when the contrast between winter and summer temperatures is excessive, as in the inferred conditions of the glacial period, then the migration of the tropical belt of high pressures would be increased over its present moderate measure. When it moved further towards the equator in winter than it does now, a greater area of the northern Sahara and of other similarly situated regions would be encroached upon with stormy westerly winds, and receive rainfall from the passing cyclones. While our understanding of this process comes largely from Professor William Ferrel, it is a pleasure to recognise that he had a compeer in Professor James Thomson, of Glasgow, who announced the essential explanation of the circumpolar circulation of the atmosphere over thirty years ago.

It seems, therefore, that there is an important correlation between aphelion winters on the one hand, and heavy snowfall in glaciated regions, heavy rainfall in interior basins, and increased rainfall on the outer margin of the dry belts of the torrid zone on the other hand; the essential connection between

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the first and last groups of phenomena being the more rapid circumpolar whirl of the general atmospheric circulation.

I do not offer this as a panacea for all glacial troubles; but simply as a corollary following from Croll's theory, perhaps deserving the consideration of geologists and meteorologists, along with the many other factors by which the climate of the glacial period is finally to be explained.

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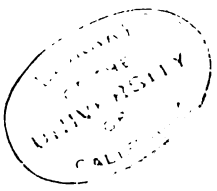

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*** JAMES HUTTON ***

By John Kay, 1787.

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY,

SESSION 1894-95.

INAUGURAL ADDRESS.

(22*nd November* 1894.)

XII.—*Old Edinburgh Geologists.* By RALPH RICHARDSON, F.R.S.E., *Hon. Secy. Royal Scottish Geographical Society; formerly Vice-President Edinburgh Geological Society.*

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IT is generally admitted that the modern science of Geology owes its fundamental principle of "Uniformity" to an Edinburgh man—James Hutton. By the adoption of this principle, which means that we should interpret the past by what we observe around us to-day, the science has been established on sure foundations, and has made great and ceaseless progress.

JAMES HUTTON (1726-1797) was born in Edinburgh on 3rd June 1726, and was the son of William Hutton, Merchant, and City Treasurer. He was educated at the High School and University of Edinburgh, and although apprenticed to a Writer to the Signet, preferred the study of Medicine to that of Law. For three years he studied medicine in the University of Edinburgh, afterwards proceeding to Paris and Leyden. At the latter University he took his degree of Doctor of Medicine. Having inherited from his father the property of Sligh Houses in Berwickshire, Hutton abandoned Medicine for Agriculture, and after studying under a Norfolk farmer, he resolutely set himself to improve the backward state of agriculture in Berwickshire, and introduced several reforms. He afterwards wrote a "Treatise on Agriculture," the MS. of which (unpublished) is in the Library of the Edinburgh Geological Society.

In 1764, Hutton made an extensive tour through the North of Scotland with his friend Sir George Clerk, and the rocks they met with and examined on the way turned his mind to geology. In 1768 he let his Berwickshire farm and removed to Edinburgh, where he became one of a distinguished literary and scientific circle, which included Adam Smith, James Watt, Dr Black, David Hume, John Home, John Clerk of Eldin, Rev. Dr Carlyle, and others. In this famous galaxy Hutton played a leading part, for he was a brilliant conversationalist. "It is impossible by words," says his biographer, Professor John Playfair, "to convey any idea of the effect of his conversation, and of the impression made by so much philosophy, gaiety, and humour, accompanied by a manner at once so animated and so simple." Hutton's personal appearance is represented in the portrait by his contemporary, John Kay, prefixed to this Address.

When Hutton began the study of geology, the doctrines of the celebrated German geologist Werner were in high repute. Werner held that igneous rocks were chemical precipitates from water. His disciples were hence called *Neptunists*. Hutton had never believed in the Wernerian theory, and at last stoutly contested it. He maintained that igneous rocks were derived from matter in fusion within the earth. His disciples were accordingly called *Vulcanists*, and the igneous rocks around

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Edinburgh formed a fitting and frequent battleground for the opposing camps.

In 1785 Hutton found clear proofs of granite being formed from matter in fusion, for, when on a visit to the Duke of Athole, he observed in Glen Tilt veins of red granite traversing black micaceous schist and primary limestone. So delighted was he with this confirmation of his theory, that his companions thought he had discovered a vein of gold. A similar triumph was enjoyed by his disciples near the "Cat's Nick" on the Salisbury Crags, where a mass of sandstone was seen pervaded in all directions by minute veins of trap. The Huttonians asserted that the trap had passed through the sandstone in a fluid state. The Wernerians denied this; so, "to settle the point, Sir James Hall had a portion of the debris cleared away, when the trap was found passing through the sandstone as the Huttonians anticipated." (*Maclaren's "Fife and the Lothians."*)

But Hutton's great principle of "Uniformity," to which reference has already been made, and his views on the gradual building-up of the rocky covering of the earth were best unfolded in papers which he read before the Royal Society of Edinburgh, and which afterwards developed into his celebrated work on "The Theory of the Earth," which was published in 1795. This work laid the foundation of the Uniformitarian, as opposed to the Catastrophic, School of Geology. It was upon this foundation that another Scotsman, Sir Charles Lyell, reared the stately edifice of his "Principles of Geology."[1]

Lyell prefixed to his "Principles" the following words of JOHN PLAYFAIR (1748-1819), Professor of Mathematics in Edinburgh University, who in his "Illustrations of the Huttonian Theory of the Earth" (published in 1802), gave, in more lucid diction than his master's, the leading principles of Hutton:—"Amid all the revolutions of the globe the economy of Nature has been uniform, and her laws are the only things that have resisted the general movement. The rivers and the rocks, the seas and the continents, have been changed in all their parts, but the laws which direct those changes, and the rules to which they are subject, have remained invariably the same." "The characteristic feature," said Lyell, "of the Huttonian theory was the exclusion of all causes not supposed to belong to the present order of Nature."

Hutton, Playfair, and SIR JAMES HALL of Dunglass, Bart. (1761-1832), were close companions, and were among the greatest of the founders of the modern science of geology. Whilst

[1] For further details regarding James Hutton, see paper by Author in vol. v. of the Society's *Transactions*, page 251.

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Hutton, by his "Theory of the Earth," originated the ideas of the new science, Playfair by his classic style gave them popularity and force. Francis Jeffrey declared Playfair's "Illustrations of the Huttonian Theory" to be a work "which must always be ranked amongst the most brilliant and powerful products of philosophical genius." Sir James Hall, again, by means of his experiments on the fusibility of rocks, earned the title of the "Founder of Experimental Geology." Nor should we forget their friend, JOSEPH BLACK (1728-1799), Professor of Chemistry in Edinburgh University, whose "discoveries," said Playfair, "mark an era, before which men were not qualified to judge of the nature of the powers that had acted in the consolidation of mineral substances."

These were not, however, the only pioneers of geology in Edinburgh at the close of the eighteenth century. JOHN WALKER, Professor of Natural History in Edinburgh University, published in 1787 his "Classes Fossilium," and in 1792 his "Institutes," whilst his interesting autobiography, which appeared in January 1822 in the Edinburgh Philosophical Journal, describes his Geological Expeditions from 1746 onwards. Then JOHN WILLIAMS, Manager of Gilmerton Coal-works, published two vols. 8vo. in 1789 on the Mineral Kingdom, in which he describes the Coalfields of Scotland, particularly the Edge Coal Seams of Midlothian. A second edition appeared in 1810, edited by JAMES MILLAR, M.D., Lecturer on Natural History and Chemistry. ROBERT TOWNSON, LL.D., described the Mineralogy of the Environs of Edinburgh in his work on Natural History, published in 1799; whilst ROBERT PATERSON, M.D., detailed the fossil organic remains in the Coal formation at Wardie in the Edinburgh New Philosophical Journal for July 1837.

More notable than these is Dr SAMUEL HIBBERT (1782-1848), whose celebrated papers on the Limestone of Burdiehouse, near Edinburgh, were read before our Royal Society in 1833-34. To the same Society its Treasurer, THOMAS ALLAN (-1833) contributed papers on fossils from Craigleith Quarry, near Edinburgh, whilst his paper, read in 1811, on the "Rocks in the vicinity of Edinburgh," was considered by Dr John Fleming a communication of great value. "Intimately acquainted," says Fleming, "with mineral species and with rocks, he has furnished the most important contributions to our knowledge of Edinburgh lithology of any member of the partisans of either Hutton or Werner." (*Lithology*).

The leading representative of science in Edinburgh during the first half of the nineteenth century was probably ROBERT JAMESON (1774-1854), who, succeeding Professor Walker, occupied the chair of Natural History in Edinburgh University for the

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lengthened period of fifty years (1804-54). He was an eminent and enthusiastic Wernerian, and was the author of a treatise on "Geognosy," published in 1808, besides various works on Mineralogy, published between 1800 and 1837. For many years he was the esteemed President of the WERNERIAN NATURAL HISTORY SOCIETY of Edinburgh, and also Editor of the "Edinburgh New Philosophical Journal." Both society and journal have long ceased to exist. Jameson's pupils include some very eminent men of Science, one of the most distinguished being AMI BOUÉ (1794-1881), who was one of the founders of the Geological Society of France, of which he was elected President in 1835. A native of Hamburg, Boué graduated in medicine in Edinburgh University, and soon afterwards published his well-known "Essai géologique sur l'Ecosse." Although trained in the Wernerian school, he was one of the chief assailants of its tenets abroad He died in Vienna, of which he was one of the leading *savants*, after a long and most eventful scientific career.

Another of Jameson's students, PATRICK NEILL (1776-1851), a well-known Edinburgh botanist and naturalist, gives us a specimen of Jameson's teaching as a Field Geologist, in a description of the "Geological Structure of the Calton Hill," in the *Edinburgh Magazine* for August 1817. Neill remarks: "The distinguished Professor of Mineralogy in our University makes it a rule to visit this hill, accompanied by the young gentlemen attending his class, and to point out the nature and relations of the rocks." Dr Neill was secretary of the Wernerian Natural History Society during its whole existence. Mainly through his exertions, the "Nor' Loch" was drained in 1820, and the West Princes Street Gardens were formed on its site. The Neill Medal of the Royal Society of Edinburgh perpetuates his memory, being the result of a bequest of Dr Neill.

Still another of Jameson's students was that celebrated Arctic explorer, SIR JOHN RICHARDSON (1787-1865), a Dumfries man, who, when a boy, enjoyed the friendship of the poet Burns. Richardson published, on his return from his second Arctic expedition, his "Fauna Boreali Americana," which at once became the standard work on the Zoology of British North America. He next devoted himself to ichthyology, and was considered the leading exponent of the science in England. His geological and geographical papers, and his books on Rupert's Land and the Polar Regions, attest his ability and industry, whilst his voyages made his name a household word.

Greater than any of these, however, was one who, in his student days, lived at No. 11 Lothian Street, a plain house

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still standing unaltered, and marked with a tablet. It was there that the illustrious CHARLES DARWIN (1809-82) resided with his brother Erasmus, and although it is said he derived no benefit from Jameson's geological prelections, the fact remains that he was one of that Professor's students during the year 1825-26.[1]

Yet another celebrated student of Jameson's must be mentioned. SIR WILLIAM E. LOGAN (1798-1875), although born at Montreal, of Scottish parents, was educated at the High School and University of Edinburgh, where he studied under Jameson. In 1842 Logan was appointed the first Director of the Geological Survey of Canada, and mapped out the geology of the vast Dominion.

In the earlier part of the century, we find (what is rare) a nobleman elucidating the geology of the neighbourhood. LORD GREENOCK (1785-1859), afterwards Earl Cathcart, read before the Royal Society of Edinburgh, in 1833, a paper on the igneous rocks of Edinburgh, more particularly the section exposed to the south of the Castle Hill, of which he gives a fine illustration. This celebrated section, where the intrusive igneous rock of the Castle is seen enveloping, calcining, and carrying up with it portions of the stratified rocks, is visible from Johnston Terrace, and Lord Greenock says it was preserved to public view through the exertions of Professor Jameson and Thomas Allan.

One of the earliest and best known general descriptions of the geology of the Edinburgh district is the essay on the Geology of the Lothians, by ROBERT JAMES HAY CUNNINGHAM, which was published in 1838, as a Prize Essay, in the Memoirs of the "Wernerian Natural History Society," accompanied by numerous plates, and a Geological Map of the Lothians by Mr Hay Cunningham. The author states that "from accompanying Professor Jameson in his excursions, he has derived much information, and has endeavoured to conduct his researches on the principles so ably taught by that experienced and celebrated geologist." He has also coloured his map in accordance with a paper by Jameson "On the colouring of Geological Maps," published in the first vol. of the Wernerian Society's Transactions. It may be added that in 1837 a Memorial from this Society, signed by Jameson, as its President, was presented to H.M. Treasury, calling attention to "the very defective state of the best existing Maps and Charts of Scotland," especially Arrowsmith's Map of Scotland, and

[1] For further details regarding Charles Darwin, see paper by Author in vol. vi. of the Society's *Transactions*, page 1.

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pointing out the impracticability of constructing a Geological Map of Scotland on which dependence could be placed until the Trigonometrical survey of Scotland was completed.

As a naturalist and palæontologist, few Scotsmen are more celebrated than JOHN FLEMING (1785-1857), a clergyman of the Established Church, who became Professor of Natural Philosophy in the University of Aberdeen, and latterly Professor of Natural Science in the New College, Edinburgh. Between 1822 and 1851 he published various works on Zoology and Meteorology, but as a geologist he is perhaps best known for his discoveries and researches in connection with the Fishes of the Old Red Sandstone. That great authority Agassiz specially visited Fleming in Aberdeen in 1840 to discuss this subject, and afterwards declared in his splendid Monograph on Fossil Fishes: "C'est sans contredit au célèbre Professeur d'Aberdeen (M. le Doct. Fleming) qu'est due la premiére decouverte de poissons fossiles dans le terrein devonien." Fleming was not only the first to discover fish remains in the Old Red, but he was also the first to announce that the Old Red is a fresh-water formation. As Sir Andrew C. Ramsay remarked in 1880, in his Presidential Address to the British Association: "In the year 1830, the Rev. Dr Fleming of Edinburgh read a paper before the Wernerian Society, in which he boldly stated that the Old Red Sandstone is a fresh-water formation of older date than the Carboniferous Limestone. This statement, however, seems to have made no impression on Geologists till it was revived by Godwin-Austen" in 1856. A treatise by Dr Fleming, on "The Lithology of Edinburgh," was published in 1859, and besides its geological value, contains interesting historical references to the old Edinburgh Geologists who preceded him.

Among these was WILLIAM NICOL (1768-1851), to whom, as Fleming remarks, "the students of fossil organisms are indebted for the processes by which thin slices of petrifactions can be prepared so as to permit the application of the microscope to the examination of their intimate structure." At the Aberdeen Meeting of the British Association in 1885, Professor Judd, in his Presidential Address to the Geological section, observed: "I cannot refrain from reminding you that while the initiative in the application of the palæontological method of research was taken by an English land-surveyor (William Smith), we are indebted to a Scotchman in an equally lowly station of life for overcoming some of the first difficulties in connection with petrographical study. Many microscopists had employed their instruments, and sometimes with useful results, in the study of the powders and the polished surfaces

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of rocks, but it is to William Nicol of Edinburgh, the inventor of the well-known polarising prism which bears his name, that we owe the discovery of the method of preparing transparent sections of fossils, crystals, and rocks, whereby their internal structure may be examined by transmitted light. Nicol bequeathed his preparations to his friend ALEXANDER BRYSON, and some of them are now preserved in the British Museum." He invented the now famous "Nicol's prism" in 1828. Another local geologist of note was WILLIAM RHIND, whose "Geology of Scotland" was published in 1842, and his "Geology of the Environs of Edinburgh" in 1846,—two little handbooks suited for the pocket of the Field Geologist, and indicating the growth of a taste for the science among the general public.

The next geologist to be mentioned was one of those extraordinary geniuses whose name and fame are world-wide. To sterling scientific claims, HUGH MILLER (1802-1856) added literary and oratorical attainments of a character which commanded universal attention. Never before had science been promulgated with such eloquence, poetry, or power. Geology was at last removed from arid discussion in academic societies, and made the daily thought and delight of the humblest working-man. Thus Hugh Miller touched with magic wand the science to which he had devoted himself, and, by popularising geology, gave its study an impetus which it has ever since felt. Miller learnt geology in a thoroughly practical manner by becoming apprentice to a stonemason at the age of seventeen, and working in the quarries near Cromarty. His active, intelligent mind did not, like that of so many masons and quarriers, rest satisfied with the mere hewing of stones, but enquired as to their nature, history, and contents. "It was the necessity," he said, "which made me a quarrier, that taught me to be a geologist." On attaining majority, Miller left Cromarty for Edinburgh, and worked there as a mason at various important buildings. In spite of his splendid physique, however, the dust of stone-hewing began to tell on his lungs, and he returned to the North, where he narrowly escaped being recruited as a Grenadier by a zealous recruiting-sergeant, who had taken a fancy to his stalwart appearance.

Devoting himself to literature and geology during his leisure hours, the Culbin Sands, near Forres, with their weird history, early attracted his attention and awoke his imagination. Then the tremendous hurricane of 1830 which swept over the North of Scotland, felling 4000 trees in a single hour at Cromarty, led him to muse on this possibly furnishing a key to the formation of Scottish morasses. "Much of the interest," he remarks, "of a science such as geology must consist in the

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ability of making dead deposits represent living scenes." At last Miller discovered, to his delight, fish-remains in the Old Red Sandstone near Cromarty, and from this date (1830) devoted himself to, and became a leading authority on, the Old Red. In 1841 he published his celebrated treatise on "The Old Red Sandstone, or New Walks in an Old Field," and dedicated it to that distinguished Scottish geologist, Roderick I. Murchison, then President of the Geological Society of London, and who himself came from the Cromarty district.

Hugh Miller appeared at a time when the air of Scotland, and notably its capital, was full of ecclesiastical strife, and when any heterodox views were regarded with suspicion and dislike. As a geologist he had to explain the Creation of the World to popular audiences tormented with the idea that their faith was in danger. Apparently he issued triumphantly from the ordeal, for he was intrusted with the editorship of a most orthodox religious organ published in Edinburgh. Occasionally he broke away from ecclesiastical trammels, and refreshed himself with a geological holiday, as is proved by his "Cruise of the Betsey, or a Summer Ramble among the Fossiliferous Deposits of the Hebrides"; his "Rambles of a Geologist, or Ten Thousand Miles over the Fossiliferous Deposits of Scotland"; and his "Geology of the Bass Rock." But such a work as his "Footprints of the Creator, or the *Asterolepis* of Stromness," published in 1849, shows that strange blending of religion and science which formed the characteristic of the period. Another work of the same nature, entitled, "The Testimony of the Rocks, or Geology in its bearings on the Two Theologies, natural and revealed," was published in 1857, after Miller's death, under the editorship of Dr John Fleming. Miller's contention throughout is that "Geology, rightly understood, does not conflict with Revelation."

At this stage, it may be convenient to refer to various eminent men who advanced the science of geology, and who were more or less connected with Edinburgh. Among these was that celebrated pioneer of geology, JOHN MACCULLOCH (1773-1835), whose "Geological Map of Scotland," "Treatise on Rocks," and "System of Geology," old-fashioned though they may be, showed the grasp of his mind and the wide scope of his investigations, whilst his letters to Sir Walter Scott during his tour through Scotland are full of interesting and valuable scientific ideas. Macculloch graduated in medicine in Edinburgh University, and was in 1811 employed by Government on geographical and other scientific research in Scotland.

SIR THOMAS DICK LAUDER (1784-1848) and SIR WILLIAM JARDINE (1800-1874) were two baronets of scientific distinction

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who paid much attention to geological phenomena. The former's contributions regarding Scottish earthquakes, the Moray floods, and the parallel roads of Lochaber, are well known. The latter's researches among the Permian sandstones of Dumfriesshire, and his discovery of reptilian footprints there, besides his general contributions to science, are justly held in esteem. As a University city of the first rank, Edinburgh has always had celebrated geologists among her professors. That distinguished naturalist and geologist, EDWARD FORBES (1815-1854), held the chair of Natural History in Edinburgh University after Jameson's death; and his equally celebrated namesake, JAMES D. FORBES (1809-1868), occupied that of Natural Philosophy in the same University until he became Principal of the University of St Andrews. His devotion to the study of Glaciers, and his elaborate investigation of their nature, will ever render his name famous in the field of physical geology.

It was in 1840, however, that the Edinburgh School of Geology received new strength and vigour, for the renowned Swiss Geologist, LOUIS AGASSIZ (1807-1873), then visited Scotland and unfolded his "Glacial Theory" to her geologists. Little did he then imagine that, of all his disciples, none would, in after years, spread his teachings more successfully throughout the scientific world than natives of the city of Edinburgh. Agassiz attended the meeting of the British Association, which was held in Glasgow in September 1840, and discussed with Murchison and Hugh Miller, in the Geological Section, the Fishes of the Old Red Sandstone. Then they had a field-day on Glaciers, when Agassiz introduced his Glacial theory, and Murchison opposed it. Undeterred, however, and fully convinced that he would find in Scotland ancient vestiges of the same glacial action which he had seen in active progress amid his native Alps, Agassiz, accompanied by his one British disciple, Dr Buckland, started for the Highlands. He found there, as he had anticipated, evidences of the same glacial phenomena as occurred in Switzerland. From Fort Augustus he wrote, on 3rd October 1840, to Professor Jameson, Editor of the "Edinburgh New Philosophical Journal," as follows:—"After having obtained in Switzerland the most conclusive proofs that at a former period the glaciers were of much greater extent than at present, nay, that they had covered the whole country, and had transported the erratic blocks to the places where these are now found, it was my wish to examine a country where glaciers are no longer met with, but in which they might formerly have existed. I therefore directed my attention to Scotland, and had scarcely arrived in Glasgow when I found remote traces of the action

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of glaciers, and the nearer I approached the high mountain-chains, these became more distinct, until at the foot of Ben Nevis, and in the principal valleys, I discovered the most distinct *moraines* and polished rocky surfaces, just as in the valleys of the Swiss Alps in the region of existing glaciers; so that the existence of glaciers in Scotland at early periods can no longer be doubted. The parallel roads of Glen Roy are intimately connected with the former occurrence of glaciers, and have been caused by a glacier from Ben Nevis. The phenomena must have been precisely analogous to the glacier-lakes of the Tyrol, and to the event that took place in the valley of Bagne. It appeared to me that you would be glad to be able to announce, for the first time, in your extensively-read Journal, the intelligence of the discovery of so important a geological fact."

Writing to Agassiz from Taymouth Castle, in October 1840, Buckland announced to him, "Lyell has adopted your theory *in toto*." On the 20th of that month Agassiz was in Edinburgh, viewing the glaciated rocks there in company with Charles Maclaren, editor of the *Scotsman*, who, in its columns, was the first to promulgate his theory in a popular form. Maclaren took Agassiz to a quarry on the south side of Blackford Hill, where the surface of the rocks was scarred with *striæ*. Agassiz instantly exclaimed, "That is the work of the ice." Two years later, Agassiz contributed an important article, on "The Glacial Theory and its Recent Progress," to the "Edinburgh New Philosophical Journal," accompanied by a map of the Glen Roy region.[1]

An eminen English geologist, whose Life was published last month, WILLIAM BUCKLAND, D.D., Dean of Westminster (1784-1856), visited Edinburgh with Agassiz in 1840, and the same year read before the Geological Society of London a paper on the "Proofs of the former extension of Glaciers in Scotland and England," in which he refers to a cliff at Blackford Hill as a natural vault, "the sides and roof of which are highly polished and covered with striæ, irregularly arranged with respect to the whole area, but parallel over limited extents." He also wrote triumphantly to Agassiz, when the latter had returned to Switzerland, "I expect Murchison will be converted by the inspection of the moraines near Lyell's house. I have found similar polish and scratches on the rock of Edinburgh Castle, and have sent an artist to daguerrotype them."

THE EDINBURGH GEOLOGICAL SOCIETY was founded in 1834 by a band of enthusiastic Huttonians, who met in the class-

[1] For further details regarding Louis Agassiz, see paper by Author in vol. iv. of the Society's *Transactions*, page 247; also the Obituary Notice, by Author, in vol. ii., page 285.

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room of ALEXANDER ROSE, Lecturer on Geology and Mineralogy, 1 Drummond Street, and ordained that a portrait of Hutton should be affixed to the Society's diplomas. Its Patrons were successively SIR RODERICK I. MURCHISON (1792-1871), who founded in the University of Edinburgh a chair of Geology and Mineralogy, of which the successive occupants have been Presidents of the Edinburgh Geological Society; and SIR CHARLES LYELL (1797-1875), who, as has been said, so splendidly established the principles enunciated by Hutton. Among the more eminent deceased Presidents of the Society, the name of CHARLES MACLAREN (1782-1866) is a household word in Edinburgh. Editor of its most influential newspaper—the *Scotsman*—the first writer to suggest (in 1824) that the locomotive would enable the public to travel expeditiously, and an admirable geologist, Maclaren occupied a leading place in the Modern Athens. His "Select Writings," published in 1869, evince the wide scope and catholicity of his opinions, whilst his "Geology of Fife and the Lothians," published in 1839, has always been regarded as one of the most trustworthy treatises ever penned. A second edition appeared in 1866, dedicated to the Edinburgh Geological Society. Another of the Society's Presidents was DAVID PAGE (1814-1879), a well-known writer of educational works on geology of great merit, and an admirable lecturer. He was appointed, in 1871, Professor of Geology in the Durham University College of Physical Science at Newcastle-upon-Tyne.[1] Another President was DAVID MILNE HOME (1805-1890), a Scottish country gentlemen with large estates in Berwickshire, who devoted a long life to scientific pursuits. His memoir on the Mid-Lothian and East Lothian Coalfields, which appeared in 1838, early established his reputation, whilst his contributions regarding British, and especially Scottish, earthquakes in the "Edinburgh New Philosophical Journal" of 1842 onwards, interested a wide circle of readers. Milne Home defeated Charles Darwin over the Glen Roy problem, as Darwin himself admitted, although Milne Home's own theory has not gained many converts. An opponent of the advocates of extreme glaciation, Milne Home devoted much time to the study of the glacial phenomena of Scotland. He was Convener of the Boulder Committee of the Royal Society of Edinburgh, and drew up ten valuable reports. He also published a book on the "Estuary of the Forth" in 1871, and another on "Ancient Water Lines" in 1882.[2]

[1] For further details regarding David Page, see the Obituary Notice by Author in vol. iii. of the Society's *Transactions*, page 220.

[2] For further details regarding David Milne Home, see the Obituary Notice by Author in vol. vi. of the Society's *Transactions*, page 119.

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With regard to deceased Vice-Presidents of the Society, two may be mentioned. The first, JAMES BRYCE (1806-1877), came from the North of Ireland to Glasgow and afterwards settled, in Edinburgh. He specially distinguished himself by his elucidation of the Geology of Arran, Bute, the Cumbraes, Skye, and Raasay. His valuable paper, "On the Jurassic rocks of the islands of Skye and Raasay," was read before the Geological Society of London in 1873, and it was well remarked that Bryce completed, by means of palæontology, what Macculloch had only begun. He was appointed Convener of the British Association's Committee on Earthquakes, and described to the Edinburgh Geological Society in 1876 the ingenious appliances of which he made use in order accurately to observe and register the faintest seismic tremors. Next year he perished whilst geologising alone among the precipitous rocks of Inverfarigaig, near Foyers, Inverness-shire, and a memorial erected by his brethren of the hammer now marks the tragic spot.[1] Another of the Society's Vice-Presidents was HENRY CADELL (1812-1888) of Grange, Linlithgowshire, whose prolonged experience in the art of mining ripened into an extensive knowledge of the geology of central Scotland. When managing the Duke of Buccleuch's collieries at Dalkeith, Cadell called Hugh Miller's attention to the tracks of reptiles in the carboniferous strata, and Miller refers to this in his "Testimony of the Rocks." Cadell's discovery of a Roman tablet on the sea-coast at his estate of Grange caused Lyell to change the opinion that he had expressed in his "Antiquity of Man," that the coast of Scotland had risen since Roman times. Cadell's only published paper, "On the Geological Features of the Upper Coal Basin of the Firth of Forth," was read before the Edinburgh Geological Society in 1870, and formed a valuable contribution to its *Transactions*.[2]

An Associate of our Society, WILLIAM MURPHY (1797-1869) resident in Edinburgh, produced a "Historical and Statistical School Atlas," a "Classical Historical Atlas," and a table showing the "Crust of the Earth," prepared under direction of our Society; whilst our Society's well-known Treasurer, GEORGE LYON (-1880), wrote a "Sketch of the Geology of Scotland," which Murphy illustrated with a map.[3]

[1] For further details regarding James Bryce, see the Obituary Notice by Author in vol. iii. of the Society's *Transactions*, page 142. Dr Bryce's son is the Right Honourable James Bryce, M.P., the eminent historian.

[2] For further details regarding Henry Cadell, see the Obituary Notice by Author in vol. v. of the Society's *Transactions*, page 502.

[3] For further details regarding George Lyon, see the Obituary Notice by Author in vol. iv. of the Society's *Transactions*, page 1.

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Physical geography and geology being such closely allied sciences, we should not forget the name of a celebrated Scottish lady who resided in Edinburgh for some time, and who was one of the leading exponents of physical science. MARY SOMERVILLE (1780-1872) was the daughter of Admiral Sir William Fairfax, and was born at Jedburgh. Her work, "On the Connexion of the Physical Sciences," was published in 1834. In 1848 appeared her equally well-known "Physical Geography," which opens appropriately with a chapter on geology, in which she discusses the geological history of the earth. It was of this work that Baron Humboldt wrote to Mrs Somerville in 1849, and said, "Je ne connais dans aucune langue un ouvrage de Géographie physique que l'on pourrait comparer au vôtre." It passed through many editions. Mrs Somerville, who had married her cousin, William Somerville, in 1812, was a great traveller, and after witnessing a splendid eruption of Vesuvius in 1872, she died at Naples, aged ninety-two.

Before closing this sketch of old Edinburgh Geologists, reference must be made to several others who have cast distinction upon the Scottish metropolis. ROBERT CHAMBERS (1802-1871) began geological investigations late in life, having previously devoted himself to literary and antiquarian pursuits, gaining thereby the friendship of Sir Walter Scott. His brother William and he started and edited *Chambers' Journal* from 1832 onwards. In 1844 a singular book appeared anonymously in London, under the title of "Vestiges of the Natural History of Creation," and caused a profound sensation. Its author discussed the creation of animated things from a geological point of view, and came to the conclusion that a "Principle of Progressive Development" must be admitted. In other words, the book foreshadowed the riper teachings of Darwin and Wallace. Great curiosity was evinced as to the authorship of this work, and various distinguished persons, from Prince Albert downwards, were suspected. Even Darwin himself, then only twenty-eight, was thought a likely person, and laughingly remarked to his cousin Fox, "I ought to be much flattered and unflattered," for he thought poorly of the geology and zoology of the work, which, however ran rapidly through eleven editions. It was not till 1883, or thirty-nine years after its first publication, that the secret was revealed that Robert Chambers, who had been dead for twelve years, was the author of this remarkable book. Living in severely orthodox times, his brother William would not allow the secret to be divulged; and so the comedy was played out of a scientific work of merit being left unfathered because its author and his friends were ashamed or afraid to acknowledge it. Robert Chambers, however,

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suffered in spite of every precaution, for he forfeited nomination to the position of Lord Provost of Edinburgh in 1848 on account of the suspicion having got abroad that he had something to do with so dangerously heterodox a work. Of course, this occurred in the middle, and not at the end, of the nineteenth century. In 1848 Chambers published his "Ancient Sea Margins," wherein he graphically represents Scotland as having, in recent geological times, been largely submerged by the sea. Occasionally he pushes his theory too far, as when, forgetting the principles of river-action as taught by Playfair, he describes the sea rolling grandly up into the furthest recesses of the Highlands, and forming the terraces of the Tay. But the book is otherwise of much value and interest. Chambers made expeditions to Switzerland, Norway, the Faroe Islands, and Iceland for the purpose partly of studying phenomena connected with the Glacial theory of Agassiz, and afterwards published books entitled, "Tracings of the North of Europe," and "Tracings in Iceland and the Faroe Islands." At the Liverpool Meeting of the British Association, in 1854, Chambers read a paper, "On the great Terrace of Erosion in Scotland," and "Further Observations on Glacial Phenomena in Scotland and the North of England."

Another eminent man, who, although he eventually settled and died in Edinburgh, could scarcely be localised, as he had geologised in nearly every corner of Great Britain, was CHARLES WILLIAM PEACH (1800-1886), who began life as a private in the Coastguard service at Norfolk. From there he was moved successively to the coasts of Dorset, Devonshire, and Cornwall, and wherever he went he devoted himself to the study of the geology and natural history of the neighbourhood. So great was his scientific knowledge of Cornwall, that he acquired the title of the "Cornish Naturalist," and in 1841 he read a paper "On the organic fossils of Cornwall" before the British Association at Plymouth. In 1849 Peach was transferred, as Comptroller of Customs, from the South to the North of Britain —from Fowey to Peterhead. In 1853 he was removed to Wick. There he made the acquaintance of that remarkable man, Robert Dick, Baker of Thurso, the Geologist and Botanist whom Dr Smiles has so worthily celebrated. Peach soon afterwards did important palæontological work, being the first to discover fossils in the limestone of Durness in Sutherlandshire, much to the satisfaction of Sir Roderick Murchison, who was thereby enabled to complete his arrangement of the system of rocks there. At the Liverpool Meeting of the British Association, in 1854, Peach exhibited specimens of Old Red Sandstone from Caithness, containing bitumen and silicified wood. Next year Murchison and

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Professor James Nicol visited the N.W. Highlands, and were accompanied by Peach as the discoverer of the key to the succession of the rocks. In 1859 the Geological Society of London awarded its Wollaston Medal to Charles Darwin, and the balance of funds to Charles Peach for his discoveries in geology, the President (Professor Phillips) acknowledging "the advantages accruing to Geological Science from Peach's researches among the oldest Palæozoic rocks, both at the southern and northern extremities of the island, he having been the first to find fossil remains in the old altered rocks of Sutherlandshire and Cornwall." Peach left Wick in 1865, and settled in Edinburgh, where he received the Neill prize of the Royal Society for 1871-74.

Another palæontologist of celebrity, THOMAS DAVIDSON (1817-1885), was born in Edinburgh, near which his estate of Muirhouse was situated. He studied at Paris, and early acquired an extensive knowledge of the geology of the country surrounding the French capital. Then he entered Edinburgh University, and soon after, by the advice of the eminent German geologist, von Buch, he devoted himself to the special study of the Brachiopoda, mollusca which are found from the Cambrian rocks up to the present day. This became the business of his life. In 1849 he prepared a monograph of British Fossil Brachiopoda for the Palæontographical Society of London. His magnificent work on Fossil Brachiopoda, consisting of five quarto volumes, containing 2350 pages of letterpress and 238 quarto plates, comprising 7910 figures, was completed in 1883, after a labour of thirty-three years. Davidson lived latterly in Brighton, where he took a leading part in every intellectual movement. In February 1865 he received from the Geological Society of London the Wollaston Gold Medal, and in December 1870 he was awarded the Gold Medal of the Royal Society of London, in recognition of his valuable contributions to Palæontology. In 1880 he was deputed by the Councils of ten of the principal Scientific Societies in London, Edinburgh, and Dublin to represent them at the celebration of the fiftieth anniversary of the foundation of the Geological Society of France. Although resident in the South of England, Davidson was warmly attached to his native land. Writing to myself in 1883, he said, "I always wish to be considered as a Scottish geologist and palæontologist, as I was born at 8 Heriot Row, Edinburgh, and all my relatives are Scotch." In 1872, in a letter which I received from him when I was Hon. Secretary of this Society, Davidson urged the importance of the study of Palæontology, and advocated the appointment by the Society of a Committee to prepare a list of the fossils discovered in the three Lothians

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and Fife. A Committee was accordingly appointed, which prepared and submitted to Davidson, in 1875, a catalogue of the Fossil Brachiopoda of the Lothians and Fife, which was published in vol. iii. of the Society's *Transactions*, page 68, with an Introduction by the greatest living authority on Brachiopoda, Davidson himself.[1]

Nor must we forget another good friend of our Society, Sir ANDREW CROMBIE RAMSAY (1814-91), who, in 1872, succeeded Sir Roderick Murchison as Director General of the Geological Survey. His works on Arran, North Wales, and the Physical Geology and Geography of Great Britain are celebrated; he resided some time in Edinburgh; and as Director of the Survey he superintended the preparation of the Survey Maps and Memoirs descriptive of the Geology of the Edinburgh district.

Among those who, in latter times, have done most to extend our knowledge of the geology of Scotland, was JAMES NICOL (1810-1879), who was born in Peeblesshire, and studied under Jameson at Edinburgh University, afterwards proceeding to the Universities of Berlin and Bonn. Returning to Scotland, he diligently investigated the rocks of his native Lowlands, and, by discovering graptolites in them, was the first to demonstrate that the main mass was of Silurian age. After publishing a "Catechism of Geology," and Essays on the Geology of Peebles and Roxburgh, written for the Highland Society of Scotland, Nicol published, in 1844, his "Guide to the Geology of Scotland," a meritorious work, to be followed, in 1858, by his "Geological Map of Scotland." His aptitude for geological research being widely known, he was, in 1847, appointed Assistant Secretary to the Geological Society of London, and edited its Quarterly Journal. In 1849 he published his text-book on Mineralogy, and the same year he was appointed Professor of Geology in Queen's College, Cork. Next year he was working in Edinburgh at his old geological field, for we find Murchison writing, in 1850, to Sedgwick in the following characteristic strain:—"When I came out of the Highlands (after killing a stag at Glenorchy Forest, Lord Breadalbane's), I wrote to James Nicol, who was still at Edinburgh, and who had been making clear sections of the Lammermuirs, to come and join me at Glasgow, to hunt up all the "Siluriana" of the West Coast, which he had never seen, and of which you had given such tempting accounts. After a trip on the Clyde to look at the clayslates there, we journeyed to Girvan, in the neighbourhood of which we worked right hard for a week. What with our own labours in the

[1] For further details regarding Thomas Davidson, see the Obituary Notice by Author in vol. v. of the Society's *Transactions*, page 249.

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field, and Saudy the fiddler's fossils, I was enabled to form some idea of top and bottom." Subsequently, in 1855, Murchison started, with Nicol as his companion, to investigate the rocks of the N.W. Highlands. They differed as to their character and succession, and whenever Nicol could leave the duties of the chair of Natural History in Aberdeen University, to which he had been appointed in 1853, he always returned to this geological battle-ground in the Northern Highlands. At last, in 1859, Murchison and he met face to face in the Geological Section of the British Association in Aberdeen. Presiding over the same section at the same place in 1885, Professor Judd described the encounter and Nicol's arguments, and after eulogising "the grand work accomplished single-handed by Nicol," maintained that he solved the great problem of Highland Geology in 1859. It is interesting to note that Nicol's views were based on those of Hay Cunningham and Macculloch, those old pioneers of Scottish Geology.[1]

The last geologist to be mentioned is one who, springing from a humble position, carried the philosophy of the science to a perfection entitling him to be considered a worthy successor of those founders of the Edinburgh School of Geology, Hutton and Playfair. JAMES CROLL (1821-1890) was born in Perthshire, and was trained as a wheel-wright. Owing to an accident he relinquished that employment, and was appointed janitor in Anderson's College, Glasgow. A treatise by him on Theism had appeared anonymously in 1857, but what first attracted public attention was his series of articles, "On the physical cause of the change of climate during the glacial epochs," which appeared in the *Philosophical Magazine* of 1864 onwards. These investigations culminated in his great work, "Climate and Time," which was published in 1875, and which was considered by British and foreign men of science to mark an epoch in the history of geology. It was hailed as a work which, for philosophical breadth and deductive analysis, had not been equalled since the publication of Hutton's "Theory" and Lyell's "Principles." His overthrow of Maury's and Carpentre's theories of Ocean circulation was considered complete. But it was the evidence bearing on former glacial epochs which made the work celebrated in geological literature. Croll announced, from astronomical and physical data, that, by extreme eccentricity of the earth's orbit, combined with the precession of the equinoxes, cosmical changes of climate were occasioned which had led in the past and would lead in the future to the occurrence of glacial epochs. In 1867, Croll had

[1] For further details regarding James Nicol, see the Obituary Notice by Author in vol. iii. of the Society's *Transactions*, page 245.

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been appointed a member of the Geological Survey of Scotland, and in 1869 he read before the Edinburgh Geological Society a valuable paper, "On two River-channels buried under drift belonging to a period when the land stood several hundred feet higher than at present." These ancient River-channels cross Scotland from the Firth of Clyde above Bowling to the Firth of Forth at Grangemouth, much in the direction of the present Forth and Clyde Canal. In 1885 Croll published his "Discussions on Climate and Cosmology," and in 1889 his "Stellar Evolution," in both of which he continued the researches which have made his name famous all over the scientific world.

With the name of JAMES CROLL, I shall fittingly close this roll-call of old Edinburgh Geologists. It is indeed an interesting portrait-gallery through which I have, however unworthily, conducted you. We saw the rise of the Edinburgh School of Geology, the little band of Pioneers of our science consisting of HUTTON, HALL, BLACK, and PLAYFAIR. We saw the torch of geology held aloft in this city for fifty years by the energetic Professor JAMESON. We saw students pass from his class-room and become eminent geologists at home and abroad, such as CHARLES DARWIN, AMI BOUÉ, President of the Geological Society of France, SIR WILLIAM LOGAN, first Director of the Geological Survey of Canada, SIR JOHN RICHARDSON, and others. We saw the geology of Edinburgh explored and described by HIBBERT, ALLAN, FLEMING, and HAY CUNNINGHAM. We saw religious men viewing the progress of science with needless alarm, and ROBERT CHAMBERS forfeiting nomination to the position of Lord Provost of Edinburgh because it was suspected that he was the author of the "Vestiges of the Creation." Then we saw the Poetry of Science exemplified as it never was before or since, by the genius of HUGH MILLER. Finally we saw the details of our science, physical and palæontological, worked out in a masterly manner by representatives of the Edinburgh school, by officials of the GEOLOGICAL SURVEY resident in Edinburgh, and by members of the EDINBURGH GEOLOGICAL SOCIETY, like its famous president CHARLES MACLAREN, Editor of the *Scotsman*, whose columns were the first to popularise the glacial theory of Agassiz, who visited Edinburgh and Maclaren in 1840, Dr DAVID PAGE, THOMAS DAVIDSON of Muirhouse, and DAVID MILNE HOME. All this we have seen, and we should be dull indeed if we did not take pride in those old Edinburgh Geologists who founded and kept alive a school of thought and progress than which none has more glorious memories or greater fame.

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XIII.—*Notes on the Sutherland Goldfield.* By EDWARD GREENLY, F.G.S., H.M. Geological Survey. (*Communicated by permission of the Director-General of the Geological Survey.*)

(Read 21st February 1895.)

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3. FACTS ASCERTAINED UP TO 1893.
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6. SUGGESTIONS FOR FUTURE INVESTIGATION.

1. INTRODUCTION.

ALTHOUGH a good deal has been written concerning the gold of Sutherland, it may be useful, as there seems to be a renewal of interest in the subject, to recapitulate the information actually obtained up to the present time, including a few additional points which came to light during the progress of the Geological Survey in the auriferous area. Verbal information of any value was difficult to obtain in the district itself.

To Dr Joass, of Golspie, I must express the greatest obligation. He has aided me in every way, including the loan of important specimens, and furnished the greater part of the subjoined Bibliography.

2. BIBLIOGRAPHY.

The following papers have been published on the subject, in chronological order as nearly as possible :—

1. Notes on the Sutherland Goldfield.
By J. M. Joass, M.D. (with introduction by Sir R. I. Murchison). Quart. Journ. Geol. Socy. 1869.
2. Researches in British Mineralogy,
By David Forbes, F.R.S., &c. Phil. Mag. 1869. (One of a series, 1867-9, on allied subjects.)
3. Something from the Gold Diggings in Sutherland.
By the Author of "Frost and Fire." Odds and Ends Series, No. 22. 1869.

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4. The Sutherland Goldfields.
By Wm. Cameron. Glasgow Geol. Socy. 1870.

5. On the Matrix of the Gold in the Scottish Goldfields.
By James Bryce, M.D., F.G.S. Brit. Assn. Report. 1870.

6. The Geognosy and Mineralogy of Scotland. Sutherland. Part VI., p. 504.
By M. Forster Heddle, F.R.S.E.

7. The Geology of Sutherland.
By H. M. Cadell, B.Sc., F.G.S. 1886 and 1896.

I would draw especial attention to the paper by Dr Joass for general description, and to those by D. Forbes and Dr Heddle for chemical analysis.

These are all the papers to which I have been able to obtain references. If anyone can tell me of any others, I shall be much obliged, in order to make the Bibliography of this subject as complete as possible.

3. Facts ascertained up to 1893.

The foregoing papers contain good descriptions of the physical characters and general geology of the district, particularly the Old Red Sandstone and the Jurassic series, the crystalline schists being the rocks of which least was known at the time.

The localities also are recorded at length, and (except perhaps in the Berriedale area) it is clear that the ground has been well searched for a long distance.

Further, I would draw attention to the following points:—

a. Analyses of the gold are given by D. Forbes and Dr Heddle, from which it appears that it contains usually from 18 to 20 per cent. of silver. A button obtained from vein-quartz contained no less than 71·43 per cent. of silver, an interesting point in connection with facts which will be given below. Its physical characters, including the peculiar "hackly" surface, have been noted and described.

β. The other heavy minerals most abundant in the gravels, and which make up the principal part of the dark residues always obtained in washing, are described by D. Forbes. They are almandine garnets and dark oxides of Iron. The latter consist of titaniferous magnetite (with 8 per cent. of TiO_2), and Black Iron Glance with Ilmenite.

The vein-quartz analysed by Dr Heddle likewise yielded Ilmenite, Magnetite, and apparently also metallic Iron.

γ. The gold occurs in alluvia bordering the rivers. It is richest, of course, in pot-holes and rock-pockets, and between

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the foliation planes and in the joints of rocks exposed in the stream-beds; but occurs also in the terraces themselves, and in coarse as well as fine material, from fine silt to rough tumultuous gravel.

The lower portions of these beds are said to be richer than the upper.

It is reported also to have been found in the unstratified drift of the moors.

δ. It has *not* been found along streams running wholly or chiefly over Jurassic Rocks, Old Red Sandstone, or the Granite of the Ord.

It has been found along streams running over *all* types of the crystalline schists; but most richly where they are full of granite veins and sills.

ε. With regard to its having been found *in situ*—

i. Dr James Bryce states that gold was washed by workmen from the powder of granites, the specimens being selected by himself at Suisgill.

ii. The vein quartz sent to Dr Heddle for analysis contained an "electrum-like" alloy (Au. 28·57, Ag. 71·43) in the proportion of 39·2 grains per ton.

iii. Gold was found in three pebbles, two of which are paste granites (or pegmatites?) of the type occurring at Kildonan, and the third a quartz schist or quartzite, apparently of clastic origin.

iv. Dr Joass appears to have found gold in a quartz vein examined by Dr Heddle and himself in Kildonan Burn, for details of which see Dr Heddle's paper, p. 509.

4. Facts Ascertained during the Progress of the Geological Survey.

The Geological Survey of the Kildonan area was made chiefly during the years 1893 and 1894, and all the ground in which gold was found in any quantity is now surveyed. The main valley and its tributaries from Helmsdale to Torrish Burn were mapped by Mr Hugh Miller, and from Duibh near Kildonan to Kinbrace by myself, there being a narrow strip still unsurveyed between Duibh and Torrish. Mr Miller has also surveyed the Blackwater area, and the country draining to the coast, as well as a tract about Ousedale in Caithness.

In all probability the most useful result with regard to future investigations into the occurrence of the gold will be the actual map itself.

The alluvia have been laid down upon it, the granite veins

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and sills picked out, and certain subdivisions established among the crystalline schists.

These subdivisions are as follows :—

Quartz-schist.
Granulitic biotite schist.
Flaky or flaser mica-schist.

The quartz-schist is a hard, flaggy, granulitic schist, containing a good deal of felspar and white mica. Though probably a highly altered sedimentary rock, clastic texture cannot now be detected with certainty in any but a few places. Thin seams of black minerals, chiefly magnetite (idiomorphic) and ilmenite, with probably some chromite, are not uncommon.

A good exposure is seen at Kildonan Bridge.

The pure white quartz-schist of Eireannaich differs from this Kildonan rock in several ways (not only in being a much purer and cleaner rock, but also in containing peculiar accessory minerals, particularly idiomorphic olive Tourmaline) and it is possible that they are *not* merely varieties of the same mass.

The Granulitic Biotite schist resembles the quartz-schist structurally, but contains biotite instead of muscovite, and more felspar. It is often difficult to distinguish between these two types. Good sections are to be seen in Suisgill Burn above Allt na Briste.

The flaky mica schist (as I have called it for lack of a better name) contains quartz, felspar, and both micas. Garnets are abundant in some bands, and the aluminous silicate sillimanite is very generally present. The texture differs from that of the other two, being much less regular, the micas are wavy and in large flakes, and felspar augen not uncommon. Good sections are seen at Suisgill Lodge.

These types pass into each other, but are fairly well marked out on the large scale.

With regard to the granites, nothing need, for the purposes of this paper, be added to the description given of them by Dr Joass.

Basic igneous rocks are very rare, and so also is true vein-quartz. I have only mapped three or four quartz-veins as much as two feet thick. Perhaps it may be as well to remark here that the quartz-rock of Eireannaich is not a vein-quartz, but a schist, resembling other large masses throughout the Highlands, which are of sedimentary origin.

With regard to the alluvia and drifts there is not very much to say. The sand and gravel terraces along the tributary streams are narrow, being seldom as much as 150 ft. in width, though the deposits are often pretty thick. Those along the main river reach $\frac{1}{8}$ of a mile, in the reaches which I sur-

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veyed. As a rule they are of finer material than those in the tributaries.

Almost the whole surface of the country is covered with Glacial Drift, rock being seen only in the stream courses and on the brows and tops of the hills. This drift is not a true "Boulder Clay," but is loose and sandy. In certain portions it is stratified, or at any rate beds of sand and tumultuous gravel occur, which, although they are more overlain by unstratified drift, are not separated from it by any defined surface feature. These are 150 ft. thick in the upper waters of the Suisgill. They should be clearly distinguished from the terrace-gravels. Blocks of Foliated Granite and of Diorite are pretty frequent in the drift, which must have come from the west, but the bulk of the material is of local origin. The white quartz-schist of Eireannaich is of rare occurrence, even close under the watershed. Besides these general results, which have but an indirect bearing on the question, one of more direct interest was obtained.

While mapping the upper waters of the Kildonan Burn, I found that the rocks, instead of being hard and fresh close to the surface, were decomposed to the depth of 20 or 30 ft. to such an extent that, while retaining all such structures as foliation, veining, and the like, they crumbled into sand between the fingers, and could be dug with a trowel, like some of the granites of Cornwall: and it occurred to me that by digging out and washing this material it would be possible to deal with much larger quantities of rock than by examining fresh specimens, however carefully. And therefore, if the gold were disseminated in very small quantities, there would be a far better chance of detecting it. However decomposed the rock might be, gold, if present uncombined, would not suffer, and would no more be carried away in solution than quartz: and even if combined, the instability of the compound would, it seemed, bring about a reduction to the metallic state sooner or later. So I dug and washed seventeen basins full of this, carefully avoiding all merely superficial sand that was clinging to the face of the cliff.

The rock was a fine granulitic quartz-schist, containing a fair amount of felspar, and some biotite, and so approaching the granulitic biotite-schist in type. It contained a few pegmatitic veins, but these were avoided; and a fine, sharp, even sand was obtained, composed of quartz, with 8 to 10 per cent. of felspar, and some muscovite and biotite.

Unfortunately, I omitted to measure the cubical capacity of the basin, and so cannot give more than an approximate estimate of the amount washed: but from measuring lately with a very similar basin and very similar sand, I think that it must have been about 350 lbs. From this were obtained 610 grains of

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dark residues, consisting chiefly of oxides of iron and zircon, with a little rutile and a deep-brown mica with a very small axial angle. These residues differed from those obtained from the auriferous gravel chiefly in the regular small size of the grains, and in the absence of garnet. The oxides of iron were for the most part magnetic. No visible gold was to be found, though the residues were carefully examined with a lens when spread out upon a plate, both before and after removal of the greater part of the iron oxides with a magnet: and samples were also scrutinised with the microscope.

On assaying, however, at South Kensington, the following result was obtained :—

Silver—11 dwt. 3 grs. per ton of residue.
Gold—A trace „ „ (estimated on 400 grs.)
(" Button too small to weigh.")

From which it would seem that the gold is included in the iron oxides, perhaps in the same way as it is known to exist in pyrites.

Finally, the dark residue from the gravels was found by microscopic examination, to contain, in addition to the minerals described by Forbes,—zircon, epidote, hornblende, rutile, and tourmaline.

None of the four last are abundant.

5. Deductions.

The facts now enumerated seem to me to confirm the views of Dr Joass and Dr Heddle as to the local origin of the gold.

The rarity of hornblende in the Kildonan Drift, a mineral that is fairly common in the drift to the N.W., when lenticles are present in the gneiss serves to show that at any rate the finer sandy particles have not travelled very far.

Also, the almost total absence of blocks of the white quartz schist of Eireannaich, coupled with the rarity of tourmaline in the residues, proves that even if that rock be auriferous, it cannot be the chief source of the gold.

Other reasons, such as the hackly surface of the particles, and their irregular distribution, were quoted in former papers.

With regard to the actual parent rock, the facts given in 3 δ make it clear that we must look to the crystalline schists complex. Among these, vein-quartz and basic rocks appear to me to be too rare for us to look to them wholly, in spite of the facts quoted under 3 ϵ., ii. iv. Admitting that gold has been found in quartz-veins in Kildonan, it does not follow that it is confined

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to them. The tendency of gold to segregate along with quartz seems sufficient to explain its presence in such few little quartz veins as there are in the district. And, although of course we must remember how much ground is concealed by drift, I am still inclined to think that the vein quartz of the area is insufficient to account for the gold in the gravels.

Personally I incline, with Dr Joass, to look to the granites. Without laying too much stress upon the results obtained by Dr Bryce (for details are not given in his paper by which we can feel certain that all risk of error was excluded), the two auriferous granite pebbles appear to me to be genuine, from their close resemblance to local rocks. Now of granites there is abundance in the district, and, though the matter cannot be considered as settled, perhaps the following consideration may help us.

The assay shows that, though disseminated in exceedingly minute quantities, gold does exist in the heavy minerals of the schists. And the high proportion of silver agrees with the analyses of the alluvial gold, and even more with that from the vein-quartz analysed by Dr Heddle.

But as the gold in the schists has not been found in visible particles, it is probable that the visible particles in the gravels must be aggregations from finely disseminated matter.

That there has been a great deal of migration of material in the schists during the process of metamorphism is certain, from the garnets and sillimanites they contain. That there must have been also migration of material in connection with the formation of the granites seems to me also certain: and I would call attention to the views of Mr Miller concerning the granites in his area, a very brief account of which can be found in the Annual Report of the Geological Survey for 1893.

Now, as gold certainly has a tendency to travel along with highly acid material, it seems to me quite reasonable to suppose that rocks containing gold, when permeated by a magma as acid as a granite, and by the superheated waters accompanying this, should readily yield up its gold, and that that gold should find a final lodgment in the veins and sills in which the granite eventually consolidates.

This is of course mere speculation; and our experimental knowledge of the salts of gold can tell us very little indeed concerning their behaviour under such conditions as these.

How the gold was introduced into the schists, it is, of course, quite impossible to say. The origin of the schists themselves is involved in sufficient mystery at present.

If, however, they are metamorphosed sediments, as seems probable, I would call attention to the occurrence of gold in the

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matrix of the somewhat altered conglomerate at Johannesburg (a slice of which, by the kindness of a friend, I am able to exhibit), and also to the fact that iron sulphides abound in this conglomerate, and that it was from iron oxides in the schists of Kildonan that gold was obtained.

6. Suggestions for Future Investigation.

With regard to future investigation, I would point out that the method of digging and washing decomposed rock has been tried in one instance only; and that it may yet conclusively solve the question of origin, and at the same time decide whether the gold can ever be profitably worked in the rocks as well as the alluvia.

These alluvia are not very extensive; they must sooner or later be exhausted; and I agree with Mr Cadell and Mr Miller in thinking that the unstratified drift is unlikely to be profitable.

I should suggest that decomposed portions of the flaky schist, of the granulitic biotite schist, and especially of the granites, all of which are well exposed in Suisgill Burn, should be examined in this way.

The residue should not be rejected even if gold is not visible, but I quite expect the granites will yield visible particles. It does not follow, however, that any of them are likely to be very rich, for the alluvial deposits have been concentrated from a wide area.

Finally, I would remark that in these matters residents, who can go over the ground at leisure, are much more likely (particularly if they have the survey map in their hands) to be successful than the Geological Surveyors, who have plenty to occupy their time and thoughts in the construction of the map and the general geology.

To residents, then, I would commend the further investigation of this question.

And in the event of disappointment from an economic point of view, I would point out that an unexpected scientific reward may await success. For there can be little doubt but that the history of the gold is bound up with the general history of the crystalline rocks of the district.

And while, for lack of precise knowledge of the chemistry of the compounds of silicon, we lose our way among a chaos of changing and complicated silicates, it might prove possible to track such a mineral as gold, retaining its individuality through stage after stage in the career of mineral change, and so supply a clue to some of the processes of metamorphism, intrusion, segregation, and foliation, which have combined to build up a gneissose complex such as that of eastern Sutherland.

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XIV.—*On the Orientation of Boulders.* By DUGALD BELL, F.G.S.

(Read 21st March 1895.)

IT is a common observation with regard to the scattered boulders and perched blocks, which are perhaps the most striking relics of a past ice-age in our country, that there is a general correspondence between the position of their longer axis and the direction in which they have been transported. When examined, it is usually found also that the striations upon them run lengthways, and correspond in direction with those on the solid rock beneath. From the Reports, for England, of the Boulder Committee of the British Association, and for Scotland, of the Boulder Committee of the Royal Society of Edinburgh, as well as from innumerable papers by private observers, an immense number of instances might be cited to show that the coincidence of the longer axis with the direction of movement is a very general characteristic of these masses. Frequently, also, it has been observed the sharper or lighter end of the boulder points in the direction *towards* which it was being moved, and the broader or heavier end in that *from* which it had come, showing that it was being carried or pushed forward in the position of *least resistance.*

These facts are generally known and accepted, and the conclusion drawn from them in favour of the boulders having been transported by land ice, and not by floating ice in any form, may also now be taken as one of the commonplaces of glacial geology.

But there is one point obviously bearing on this conclusion which seems not to have received the attention it is entitled to, —we mean the position occupied by boulders on the surface of existing ice-sheets. There can be little doubt, from the different levels and kinds of resting-places in which boulders are found, as well as from the different forms of the boulders themselves, that many of them were transported on the surface, while others were pressed forward beneath the bottom of the ice. Now, among all the observations which we have read regarding glaciers, we cannot say that we remember an instance in which it was stated that the boulders strewn on the surface of the ice present any general uniformity of position. Yet from the

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numerous observations, to which we have referred, of the positions of these old "erratics," this might clearly be expected.[1]

Of course all writers on glaciers take notice of the fact that the trains of rocky débris which these ice-streams carry along have always a direction parallel to the sides, but it seems not to have occurred to any to observe whether the particular stones in these trains have, or have not, on the whole, a corresponding direction. When we consider the matter, however, it seems in every way more probable that they should have such a direction than that they should have any other.

A few years ago we took an opportunity of submitting the question to an eminent Alpinist, whether he had observed any such uniformity of direction among the boulders of the Swiss glaciers, with which he was so well acquainted. The reply was that he had not observed it; but his attention had not been specially directed to the point, and he was unable to say with any certainty whether it was really the case or not.

From our own brief visits to Switzerland in recent years, we have a distinct impression (not to put it more strongly) that such a longitudinal direction in the boulders on the surface of the glaciers is very general, though not invariable. It is not invariable, because of the accidental changes of position to which, especially on small and much-crevassed glaciers, the boulders are liable. On the larger glaciers, as the Rhone, Aletsch, Unter-Aar, and Görner glaciers, we believe the great majority of the boulders, especially those of any magnitude, exhibited the longitudinal direction referred to. On the Görner glacier especially we observed several distinct trains of boulders, five or six in number, placed in a line, all similar in position, very like a little flock following a track on the mountain side. Also on the moraines we noticed that, while the smaller stones appeared to be heaped together without any order, yet, looked at more carefully, and especially with regard to the larger blocks amongst them, a very general uniformity became apparent. It seemed as if, while the smaller stones, by being moved together or against each other, were thrown into various positions, the larger masses, having a deeper or firmer hold upon the ice, and

[1] In Charpentier's classical, "Essai sur les Glaciers," a quotation is given from a letter by M. Biselx, curé at Orsières, who was president of the Helvetic Society of Naturalists in 1829. Referring to a huge block of granite which rests perched on a very narrow ledge of rock about 1500 feet above the bottom of the valley near Orsières, and to the evidence which it presents of having been deposited there very gently, otherwise it could not have remained in such a position, he says:—

"On aurait dû étudier mieux qu'on ne l'a fait l'assise des blocs erratiques comparée à celle des blocs qui entourent les glaciers de notre époque. Ce serait un travail qui jetterait beaucoup de lumière sur ce point." (P. 149.)

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influenced only by its movement, maintained a greater uniformity of direction.

When we remember how common a characteristic these longitudinal striations are of the stones in the boulder clay, even of the smallest of them, we can have little doubt that all the rocky fragments being carried forward by a glacier—whether on the surface or imbedded in the ice, or beneath it—have, as a rule, a certain uniformity of direction imparted to them by the motion of the ice. Many of the smaller fragments, indeed, are believed to have received their markings "within the matrix" by the motion of the ice itself charged with fine sandy particles, and not by any direct contact with each other or with the rock beneath.[1]

A remark by Mr F. W. Hutton of Christchurch, New Zealand, regarding the Mueller Glacier, New Zealand, may here be quoted. "The ice," he wrote, "contains in places numerous angular stones, principally of slate, scattered irregularly through it, and these fragments always have their broad or cleaved surfaces parallel to the smaller system of veins," [which, as explained, "run nearly in the direction of the glacier."] "These stones have no doubt entered the ice through the numerous moulins and crevasses which are found higher up the glacier, but as they are not found in bands nor in pipes, they must have been moved in position by the ice."[2]

Further observations of this kind are much to be desired.

The point is a minor one, yet appears to be of some interest, and perhaps others, as they have opportunities of observing the facts, may think it not unworthy of attention.

[1] Hugh Miller, F.G.S., "On Boulder-Glaciation." Proc. Roy. Phys. Soc. Edin. Vol. VIII. 1884. (P. 177.)

[2] *Nature*, 24th May 1888.

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XV.—*Note on the occurrence of* Alethopteris lonchitica *in the Carboniferous beds of Loch Ryan.* By J. HORNE, H.M. Geological Survey of Scotland.

(Read 18th April 1895.)

ALONG the western shore of Loch Ryan a narrow strip of Carboniferous rocks is represented on the published geological map of that region. It is traceable for five or six miles, and it is only a few hundred yards wide. It rests unconformably on the Silurian rocks, and is overlain in turn unconformably by a coarse dark red breccia, referred to the Permian formation. Few exposures of the Carboniferous rocks are to be seen, the surface being mostly covered with drift. The strata consist of gray, reddish, and mottled sandstones and purplish clays which have yielded a few fossils, consisting, with one exception, of plant remains in a poor state of preservation. The exception referred to appears to be the remains of an encrinital stem.

The following list of fossils, determined by Mr R. Etheridge, junior, is given in the explanation descriptive of the geology of the one inch map:—

Alethopteris lonchitica—Sternb.
Asterophyllites (like *dubia*—Brong).
Poacites (linear like plant).
Calamites dubius—Brong.
Stigmaria (like *ficoides*—Brong, with rootlets attached).

The last specimen is too indefinite for a decided opinion to be passed on it. From the presence of these organic remains, the strata containing them were provisionally referred to the Calciferous Sandstone series.

Recently, however, a contribution of the highest value has been made to our knowledge of the vertical distribution of fossil plants in the British Carboniferous rocks. In his address to the Royal Physical Society, "On the various divisions of British Carboniferous rocks as determined by their fossil flora," Mr Kidston has demonstrated the high palæontological value of fossil plants in correlating and dividing the Carboniferous rocks. He has shown that much has been done on the Continent by palæobotanists in the zonal classification of Carboniferous rocks by the aid of fossil plants. His own contribution, based on an intimate knowledge of the fossil flora of the Carboniferous

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systems of England and Scotland, throws a flood of light on the classification of these rocks.

He divides the system into two great divisions, the Upper and Lower Carboniferous, as shown in the following table:—

Upper Carboniferous	Upper Coal-measures. Middle Coal-measures. Lower Coal-measures. Millstone Grit series.
Lower Carboniferous	Carboniferous Limestone series of Scotland= Yoredale rocks of England. Calciferous Sandstone series of Scotland= Mountain Limestone of England.

From an examination of the plant remains he proceeds to state that he does not know a single species of plant found in the Lower Carboniferous division that occurs in the Upper Carboniferous. So far as he has been able to ascertain, "there is not in Britain one species common to both of these great divisions. Between the top of the Carboniferous Limestone series and the base of the Millstone Grit an enormous period of time is unrepresented by any rock in Britain—a period so great that during its existence a complete change took place in the flora."

In his valuable address Mr Kidston has prepared a table showing the vertical distribution of Carboniferous plants in Britain. One of the forms included in the small list from the Carboniferous beds of Loch Ryan, viz., *Alethopteris lonchitica* is restricted by Mr Kidston to the Upper Carboniferous division. It ranges from the top of the Coal-measures to the Millstone Grit, and has never been found below that horizon. If Mr Etheridge's determination is correct, then it would follow that the beds containing this fossil plant are at least as high in the succession as the Millstone Grit, and that the representatives of the Carboniferous Limestone series with the Lower Coals might be looked for in the Loch Ryan basin.

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XVI.—"*Note on a Band of Fossiliferous Ironstone in the Cambrian Rocks of West Ross-shire.*" By J. HORNE, Geological Survey of Scotland.

(Communicated by permission of the Director-General.)

(Read 18th April 1895.)

THE discovery of the *Olenellus* zone in the Cambrian rocks of the North-West Highlands has furnished a definite geological horizon from which to work out the succession of the strata above and below. The trilobites, recently described by my colleague, Mr Peach, F.R.S. (Q. J. Geol. Soc., vol. L., p. 661), plainly show that valuable additions could be made to our knowledge of the fauna of Lower Cambrian time in the North-West of Scotland, if favourable sections could be obtained for the exploration of this zone. Unfortunately, from the lithological character of the Fucoid shales, they frequently weather with a soft grassy feature. Hence for miles along the line of outcrop the fossiliferous bands of the Olenellus zone are concealed from view, save where a stream has cut a transverse section across the series. This feature is specially noticeable in the area lying to the west of the great terrestrial displacements in Sutherland and Ross. As it is only in the undisturbed region that any hope can be entertained of finding well preserved fossils, this phenomenon is a source of disappointment to those interested in the life-history of the older Palæozoic rocks of the North-West Highlands.

When searching the Fucoid shales on the slope of Meall Ghiubhais near Loch Maree, in 1893, Mr Macconochie observed a thin band of pisolitic ironstone about two inches thick. It there rests on the layer containing the splendidly preserved specimens of *Olenellus*, and is overlain by shales containing fragments and some complete specimens of trilobites. This thin seam of ironstone contained organisms like brachiopods, though at the time undeterminable. He further noted it in the disturbed area in Glen Cruchallie (Glen Logan), near Kinlochewe, where it is to be found near the top of the Fucoid beds, close to the outcrop of the Glen Logan Thrust plane.

In the course of my field work in the Achnashellach deer forest during 1894, evidence was obtained of the presence of this band of ironstone in the Allt nan Dearcaig, one of the sources of the Coulin river, at a point about two miles north of Achnashellach station. Here it is met with in the region affected by the dynamic movements. The lofty mountains lying to the

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west furnish admirable examples of the repetition of the Torridon Sandstone and Cambrian rocks, partly by great reversed faults and a complicated system of folding. The extraordinary alternation of great slices of Torridon Sandstone and Cambrian rocks in that region was referred to and figured long ago by Sir A. Geikie in the conjoint memoir with Sir R. I. Murchison on the North-West Highlands. The recent detailed mapping of the area proves that the complicated structure can be unravelled with marvellous accuracy by means of the zonal method.

In Allt nan Dearcaig there is an excellent section of the Fucoid shales, as the burn flows for part of its course along the strike of the beds. Unfortunately the shales are much cleaved, and though from the nature of the bands one can recognise the *Olenellus* zone in its proper position underneath the Serpulite (Salterella) Grit, still it is almost hopeless to expect to find recognisable fragments of trilobites. On the hill slope on the east side of the stream the outcrop of the Coulin Thrust can be followed, bringing forward a slice of Lewisian gneiss and deformed Torridon Sandstone. Though the Fucoid shales are highly cleaved, the band of ironstone forms a conspicuous feature at one point in the bed of the stream, reaching a thickness from 18 inches to 2 feet. The cleavage has not affected the band of ironstone. It is abundantly charged with one or more organisms, conspicuous on the weathered surface of the rock. From a microscopic section examined by my colleague, Mr Teall, it appears that the organic remains show structures resembling those of echinoderms—a view which is shared by Dr Hinde and Mr E. T. Newton. These fragments have their original calcite replaced by ferric oxide, in the same way as specimens of Carboniferous Limestone from South Wales. The matrix of the Achnashellach ironstone and of the South Wales specimen referred to is calcite.

In a valuable paper by Mr C. D. Walcott on "Lower Cambrian Rocks in Eastern California," published in the American Journal of Science, February 1895, he makes the following reference to the fossils found in the limestone series:—"In places the lower portion of the upper limestone is almost a solid bed of *Archæocyathinæ*. *Ethmophyllum Whitneii*, Meek, is very abundant, and the genera *Protopharetra*, *Coscinocyathus* and *Archæocyathus* occur. *Ethmophyllum* ranges throughout the limestone series into the base of the shales in Tollgate Canyon where it is associated with Cystidean plates and fragments of Olenellus."

It is not improbable that some of the organic remains in the Achnashellach ironstone may be Cystideans. Mr Peach, however, is of opinion that a Lower Cambrian brachiopod also occurs in the rock.

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XVII.—*On an Iona Erratic containing Withamite.* By James Currie, jun., M.A.

(Read 2nd May 1895.)

Not many of the tourists who every year in increasing numbers pour into the sacred island of Iona have time or indeed inclination for more than a hurried visit to the Cathedral and the ecclesiastical buildings grouped around it. Very few find their way to the ruddy headlands that front the Atlantic and to the lonely bays sheltering between them.

One of the largest of these, in the extreme south of the island, bears the name of Port na Churaich—the port of the coracle—because here, thirteen centuries ago, Columba's wandering vessel found at length a haven. The bay is the submerged portion of a small valley, bounded on both sides at the north end by heathery knolls and then by steep though not lofty cliffs, its sandy grass-covered floor sloping gently to the sea It has been formed by the gradual removal of one of the softer beds which are intercalated with the gneiss. Probably the eroded stratum was a serpentine-bearing marble, for the little bay has been the principal locality for those rolled fragments of pale green precious serpentine which are known as "Iona pebbles."

In the course of my visits to Iona I have frequently found myself at this little bay, which has a peculiar charm of its own that attracts one more and more strongly with each repeated visit. It is most pleasant on a warm summer day to sit upon the close elastic turf, sheltered from the wind, and with no sound to break the stillness but the ripple of the tide among the skerries, and the browsing of the black and dun-coloured Highland cattle. The lazy Atlantic swell rolls into the harbour, but so broken by the sheltering islands that it scarcely more than stirs the long brown fronds of the laminaria, flashing as the sunlight catches their broad and shining surfaces. Very rarely the black head of a seal may appear above the placid water, to vanish as suddenly and noiselessly; or now and then the shadow of a seagull may float past; or an unguarded movement scare the rabbits to their burrows. Nothing else is likely to disturb the solitude.

On my last visit to this spot, in September 1894, I occupied

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a few minutes in cursorily examining the larger pebbles which form in one part a broad belt between the sward and the beach proper. As was to be expected, I found the stones to consist for the most part of rolled fragments of the gneiss of the island in its various varieties, frequently, like much of the rock at this southern end, highly epidosytic. Less common, but still in considerable numbers, are pebbles of the white serpentine-bearing marble that is interbedded with the gneiss, and of the red granite of the Ross of Mull. Besides these however there is a certain small proportion of the stones clearly exotic, and derived from rocks found in place neither in the island itself nor on the land immediately adjacent. Among them was one that is interesting both as containing the rare mineral Withamite, and also because for this reason it is possible to indicate with precision the spot from which it has been derived. The specimen was a flat oval stone, entirely water worn, about 5 inches in length by 3½ in breadth, and the Withamite is distributed through it in considerable quantity.

The mineral Withamite occurs in an igneous rock, some seven miles up Glen Coe. It was discovered there by Mr Henry Witham in 1824, and was described by Sir David Brewster in the following year. Haidinger considered it to be a variety of Epidote, and it has since then been classed with that species, though it presents some unusual characteristics. The most important of these is its very marked dichroism, the crystals being red in one direction and yellow in another. Dr Heddle has shown that its composition also is not quite that of a normal Epidote, there being an excess of silica. In crystallographic form it agrees with Epidote, but it is probably better entitled to specific rank than many minerals whose claims are admitted by the text-books without question. At a time, however, when there is a tendency to multiply inordinately the number of mineral species, which are often founded on very trivial characteristics and after very imperfect examination, it is perhaps better to acquiesce in the long-established position of Withamite, and to regard it simply as a very distinct and well-marked subspecies of Epidote.

Since Mr Witham's discovery the mineral has never, so far as I am aware, been observed anywhere else, and I should have liked to add a new locality. But the specimen is so absolutely identical with those from Glen Coe, both as to the mineral itself and the rock containing it, that I fear it is quite impossible to regard it as anything but an erratic from that place.

I may mention here that I have found in Iona, but very rarely—so far only three small specimens—another rose-coloured mineral doubtless of the nature of Epidote, and which may be

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Thulite. But in this case the matrix is the ordinary gneiss of the island, and the pink mineral appears simply to take the place of the usual green Epidote of the locality.

Assuming then that our pebble is from Glen Coe, the parent vein is about sixty miles distant from Iona in a straight line E.N.E., and I presume there is no doubt that we must look to ice as the transporting medium. It would be interesting to discover whether among the boulders of Iona there are others to indicate the course taken by the ice, but in the short time I had I did not observe any that could throw light upon that aspect of the question. There were several blocks of disintegrated dolerite; but as even to-day this rock covers so large an area of Mull, these do not give us much information.

We seem, however, so far as Mull is concerned, to be shut up to a course between Ben Talla on the one hand and Ben Buy on the other; if, that is to say, the block was really transported during one of the periods of maximum glaciation. For it is not easy to see why the ice on any other route should have bent round so as to reach Iona at all. Upon this hypothesis the course must have been somewhat as follows:—

The Glen Coe glacier, after joining with that from the upper waters of Loch Leven, would unite at Corran with the large mass coming southward down Loch Linnhe from Glen Nevis and the Great Glen, and would strike upon the coast of Mull about Duart Bay. At this point it would be hemmed in on almost all sides and would also feel the pressure of the ice from Glen Etive, which would hinder its free passage into the Firth of Lorn; and this heaping up of the ice here is further indicated by the deep hollow in the Lynn of Morven, between Rudha an Ridere and the little island of Bernera. In consequence of this pressure it would to a considerable extent be forced up the slopes of Mull and round the flanks of Creag Dubh and Sgurr Dearg, and while part would no doubt reach the Firth, either directly or by Loch Buy, another portion may have been pushed up the gentle incline of Glen Lusga, and, overflowing the low col at the head of that valley, have descended towards Loch Scridain. Reinforced doubtless by local ice from the Ben More mountains on the north and deflected somewhat southward by the heights of Ardmeanach, it would pass over the low land of the Ross of Mull, and so reach the Atlantic over the island of Iona.

This would probably be the course taken even with the mer de glace at its greatest thickness, for the bottom ice would always tend to follow the line of the valleys although these might not coincide exactly with the direction of the general movement of the ice-cap. And this block—unless the vein

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occurs somewhere high up in the face of the cliff, where it has never been observed—did not fall upon the surface of the glacier, but was dragged along the floor of the glen and caught up into the lower layers of ice.

I think it is quite possible that ice from Loch Linnhe at least may have reached Iona in this way when the ice-cap was at its maximum and the pressure from the East enormous, but the glaciers of that period have already been given so much hard work to do, that it does not seem fair to burden them unnecessarily with the transport of this erratic.

There is another very obvious hypothesis.

The icebergs from the glaciers that calved into the fjords during the advance of the ice sheet, and again when it was retreating, must frequently have borne with them stones and other debris. And even during a much milder period shore or river ice may have often carried away in spring pebbles from the shores of the lochs and from the river beds. And it is not difficult to imagine one of these floes, at a time when the sea level was at least not greatly different from the present, drifting down Loch Leven and Loch Linnhe, bearing with it from the mouth of the Coe this pebble of porphyry, and after floating along the coast of Mull, finally stranded with its burden on the South end of Iona.

I am inclined to think that this is, for several reasons, the more probable explanation in this particular case. But both creeping and floating ice must I believe have contributed to the remarkably heterogeneous collections of rocks which are to be found on the shores of some of these Western islands, and which merit I think a more detailed consideration than they have yet received.

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XVIII.—*Notes on the Section in the New Haymarket Tunnel.*

By HENRY M. CADELL, B.Sc., F.R.S.E., F.G.S.

(Read 2nd May 1895.)

THE new Haymarket Tunnel, which runs parallel to and alongside of the original tunnel, has a length of about 1000 yards between the Haymarket Station at its western and St Cuthbert's Churchyard at its eastern end. The excavation was a work of great engineering skill, as the crown of the arch had at places to be constructed in soft, loose soil, a very few feet below the buildings above. At other places the whole of the excavation was in the solid rock, and while the work was in progress I had, through the kindness of Mr W. Laing, one of the engineers in charge, an opportunity of paying several visits and examining the sections as they were opened up during the winter and spring of 1893. The exigencies of the case necessitated the building in of the ring as the cutting advanced, so that the section was closed in a very short time after it was opened up. I was thus only able to catch a series of glimpses of the parts that were open at the time of my visits, and may well have missed interesting parts between. I saw, however, good samples of most of the rock that had been excavated as it was carted away, so that I was enabled to judge pretty accurately of the nature of the rock all the way along the excavation. Since this section is now quite concealed I think that perhaps some useful purpose may be served by placing on record the few observations that were then made.

Throughout the whole length of the tunnel the rocks were of a sedimentary character, and so far as I have been able to ascertain, no igneous intrusions or ash beds were met with. The general dip was to N.W. or W.N.W. At the Haymarket end there was a set of well bedded gray fakes, sandy shales, and blaes dipping to N.W. at 35°. A rib of coal, varying from 1 to 3 inches in thickness, was found about 170 feet in from the mouth of the tunnel, and a few other coal ribs were met with under Dalry Road and Morrison Street, but beyond these no other seams of coal, oil shale, or other economic rocks were found, so far at least as I was able to ascertain. The section all the way to the Lothian Road consisted of gray carbonaceous fakes, sandy ribs, blaes, and thin sandstones, with occasional hard "kingle" beds. These beds had a tolerably uniform dip to

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N.W. of 35° to 49° all the way along to the Caledonian Station, under the centre of which the tunnel was carried. Here and there I was also able to measure the dip of the beds exposed in excavations on the surface. At the south end of Palmerston Place, a short distance to the north of the line of the tunnel, the shales were found dipping to N.W. at 35°.

At the Caledonian Railway Station a large fault was clearly revealed on the surface, and in the tunnel beneath another dislocation a short distance to the north of the former was also exposed. The fault first mentioned runs parallel to the railway, right through the turntable east of Morrison Street Bridge, and thence in a N.E. direction through the centre of the goods station. It has a downthrow to N.W., and the black blaes at each side have been much smashed and are tilted up at an angle of 50°. In the tunnel a parallel fault was crossed running underneath the west end of the new passenger station, and close to this dislocation the shales were nearly vertical in position, and much disturbed. This line of dislocation may be either a separate fault or a branch from one of the great faults that have been traced for miles across the country to the west of Edinburgh. These have the effect of bringing up deeper parts of the calciferous sandstone series along their southern side, and were probably connected with the movements accompanying the upheaval of the Pentland ridge. Hitherto only one main line of dislocation has been clearly traceable on the surface in this locality. It runs along Fountainbridge, and was clearly seen when the cutting for the suburban railway was made at Craiglockhart Station. The dark shales of the Wardie series were there found to be faulted down against the red conglomerates and sandstones that are now regarded as the upper members of the Old Red Sandstone. When such large dislocations traverse a district it is usual to find several parallel faults instead of a single one, and it seems to me probable that the fault at the Caledonian Railway Station is a secondary fault of perhaps lesser magnitude than the larger one to the S.E.

At the east end of the tunnel, under St Mark's Chapel in Castle Terrace, the beds were of hard freestone and red marl, with a dip to W.N.W. of 40°. To the east of Castle Terrace the excavation was partly made through silt, deposited, no doubt, in the marsh that once occupied the upper end of the Nor' Loch valley. The only important remains of an organic nature exhumed in the section were obtained during the gruesome operation of tunnelling through St Cuthbert's graveyard, one of the coffins having been found buried 20 feet below the surface!

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY.

SESSION 1895-96.

XIX.—*Some of the Modes of Origin of Oil Shales, with Remarks upon the Geological History of some other Hydrocarbon Compounds.*

By J. G. GOODCHILD, F.G.S., H.M. Geological Survey, Curator of the Collections of Scottish Geology and Mineralogy, Edinburgh Museum of Science and Art.

(Read 2nd May 1895.)

THE origin of the native hydrocarbons has attracted a great deal of attention within the past few years, chiefly, perhaps, on account of the important economic questions connected with the subject. Yet notwithstanding the fact that various mining engineers, chemists, and geologists, each with a good knowledge of the facts, have devoted much thought to this subject, very wide differences of opinion upon the modes in which these deposits have been formed still prevail. This may be partly due to investigators giving exclusive attention to one set of occurrences, or to one particular view, without their taking into account the possibility that similar results may have arisen through the operation of widely different causes. Those who have brought extended knowledge to bear upon this difficult question know full well that no single explanation of the origin of the natural hydrocarbons is applicable to every known case. In attempting an explanation of this, as of so many other natural operations, we have therefore to keep steadily in mind at least the possibility of these products, as a whole, having originated in very different ways.

The literature connected with this subject is now so voluminous that it is next to impossible even to refer to the whole of the authors by name. Nor is it possible, or perhaps necessary, to attempt to notice more than a few of the theories which have

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been advanced regarding the origin of the hydrocarbons. In the present communication, therefore, attention will be confined to observations upon such views as have met with more or less general acceptance. To these it is proposed to add some further observations which have been suggested by a wide survey of the facts at present known.

Amongst the many views which have been advanced is one which appears to find considerable favour with geologists, and especially with those of Scotland. Noting the fact that some of the principal deposits of oil shale are found in those areas of Carboniferous Rocks where coal seams occur in intimate association with eruptive rocks, geologists have perceived in this association a case of cause and effect. It has been stated, with a good show of reason, that where eruptive rocks have made their way upward through strata containing much carbonaceous matter, this has undergone distillation, and the volatile products have risen from the parent source to a higher level where they have eventually undergone condensation. No one can for a moment deny that such a process does take place now, and we may safely affirm that it has done so in the past. But much of the evidence adduced in support of the view that such has been the case in any special district, such as in the Lothians, breaks down on closer examination. For example, one of these evidences was supposed to be afforded by the anthracite and various bituminoids which occur in connection with eruptive rocks near Linlithgow, Elie, St Andrews, the Calton Hill, Arthur Seat, and Craiglockhart Hill.[1] In regard to these bituminoids it is now known almost for certain that they are due to the effects of high temperatures upon *limestone*, by which calcium carbide has been formed. From this, by the operation of other causes (which in these days when acetelyne gas is so much used are now well understood), various solid hydrocarbons have resulted,[2] and indeed the occurrence of the *diamond* in connection with volcanic necks may well be an extreme case due to the same cause. Modern researches in chemistry have taught us that there is no necessary connection between the occurrence of such carbon compounds as graphite and anthracite (and therefore diamond) and organic agency. Hydrocarbons, in the great majority of cases undoubtedly of

[1] Specimens of these minerals from each of these localities are on view in the Heddle Collection, now exhibited in the Gallery of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art.

[2] This explanation of the origin of the anthracite of the Calton Hill, &c., was first made public by the writer of this, at the meeting of the Edin. Geol. Socy. in Feb. 1897.

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organic origin, may also arise through the operation of causes of a purely inorganic nature, in like manner to limestones, as I have before shewn (Proc. Roy. Physical Socy., vol. x. p. 98 (1889). Geol. Mag., Feb. 1889. Trans. Edin. Geol. Soc., 1889).

Assuming, however, that certain hydrocarbons may arise through the distillation of the volatile constituents of coal-seams by the heat from contiguous eruptive rocks, let us briefly consider what form the results would take. Several factors are concerned in such an operation. Amongst these may be stated —(1) The chemical composition of the seam when first affected by the heat emanating from the intrusive mass. (2) The temperature of the molten mass, its chemical composition, and the period through which it remained hot. (3) The lithological character of the sedimentary rocks affected by the intrusive mass, the distance of the coal seam from the bounding surfaces of the molten rock, and the thickness of rock overlying both. (4) The quantity of water present. (5) The form of the intrusive mass, whether a sheet, a dyke, or a neck rock. Given a series of coal-bearing strata, which are overlain by other strata of a suitable kind, and are afterwards invaded by a *sill* of eruptive rock, and we have all the conditions requisite for the distillation, and the subsequent condensation at a higher level, of such hydrocarbons as are volatile at the temperature to which the rocks were raised. It would probably not be at all difficult to point to many cases in the Lothians, and probably elsewhere also, where this combination of conditions may have given rise to the results here indicated.

On the other hand, as perhaps might have been expected, there exist many cases to which the explanation just given would not seem very well to apply. We can, perhaps, best approach the study of these after considering how eruptive rocks would affect carboniferous strata under conditions different from those just mentioned. It is undoubtedly true that, in *replacing* the rocks they invade, intrusive masses do very frequently keep to one definite geological horizon, and they do this, in some cases, over hundreds of square miles. The Whin Sill of the North of England is a case in point. But quite as often they cut across the bedding at every imaginable angle. An intrusive mass may thus directly underlie a given coal seam at one point, while at another, only a few yards off, the same intrusive mass may lie on a geological horizon higher or lower by many yards. In all cases of intrusion the isogeotherms—if one may so term them—resulting from the intrusion of the heated mass, must range approximately parallel to the bounding surfaces of the intruder, except, of course, where marked differences of thermal conductivity exist in the rocks so invaded. In the case of an intrusive

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mass which cuts across the bedding of the rocks instead of conforming to it, both the distillation and the subsequent condensation of any hydrocarbons must therefore be, from the very nature of the case, extremely irregular, and quite unlike the regularly-stratified beds confined to one definite geological horizon, with which we are accustomed to meet in the case of beds of oil shale. The most that could happen in such a case would be the formation of a series of carbonaceous aureoles on horizons where suitable conditions for the redeposition of the hydrocarbons existed in the neighbourhood of the intrusive mass.

The next point to be noticed is the very important one, that coal-bearing strata which have been invaded by intrusive sheets occur in districts where oil shales are quite unknown. In the Upper Carboniferous Rocks of the Basins of the Forth and the Clyde there is a concurrence of such conditions, and yet oil shales on these horizons are either imperfectly represented or else are altogether absent.

On the other hand, confining our attention to the Lothian Oil Shales for the present, we find that they are practically all restricted to one geological horizon in the Lower Carboniferous rocks, which horizon is in the strata between the Hurlet Limestone (which is of Yoredale age) and the top of the Sandstones of Salisbury Crags (which sandstones correspond in position and lithological character to the Lower Limestone Shales of English geologists). True coal seams within the boundaries named are rare, and are almost never of any great thickness. Again, it is by no means the case that the oil shales are confined to the neighbourhood of the intrusive rocks. Mr Cadell's well-known and valuable paper on the "Oil Shales of the Lothians" —Trans. Mining Institute of Scotland—and his equally valuable work on Sheet 32 of the Geological Survey of Scotland, have given geologists abundant opportunity of making themselves fully acquainted with both the geological position and the geographical distribution of these deposits in the district referred to, so that we need no longer remain in doubt in regard to the facts.

Field evidence throws a certain amount of light upon the relations which the oil shales bear to associated deposits of sedimentary origin. Regarded as they occur over a large area, they are seen to form members of a series of deposits which have carbonaceous shales and sandstones as their chronological equivalents in one part of a given area—in the direction whence the source of the materials is supposed to have lain—and coal seams and limestones in the opposite direction—that in which deeper-water conditions are believed to have prevailed. Like coal seams, some oil shales are traceable for many miles in a

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given direction, with but little variation in character; while in other cases they may pass within short distances into ordinary carbonaceous shales, into cannel coal or into blackband ironstone; or they may be interbedded with thin bands of chemically-formed limestone, generally of the type represented by the well-known limestone of Burdiehouse. Any explanations of the origin of the oil shales which is intended to apply to all the known cases must take full cognisance of these facts.

We will now pass on to consider one or two such explanations, each of which will probably be found to hold good in particular cases, but no one of which is capable of universal application. One of these views is based upon the assumption —doubtless a good one in many cases—that the carbon compounds which confer upon oil shales and allied rocks their large percentage of bituminoids, are due to the decomposition of matter of *animal* origin. Fish, mollusca—animals of any kind whose remains find their way into water, are supposed to have contributed their share.

That animal life abounded in the waters in which oil shales were deposited, no one who knows these rocks as they occur in the field can for a moment entertain any doubt. Nor is it possible to feel any doubt that, if the local circumstances were of such a nature as to arrest or to delay the processes of decomposition to which all dead animal matter is subject, the carbon, hydrogen, &c., which largely go to make up these organic compounds, might well—in fact must—go to form materials very similar in their composition to those which make up the bituminoids in question. There is no difficulty in at least conceiving that such concurrence of circumstances may again and again have arisen, both on the land and below the sea, by which dead matter of animal origin has been converted into hydrocarbon compounds. We know that, as a rule, organic matter of animal origin is very rapidly decomposed into its components, which components, when liberated under water, produce some geological effects of considerable importance. What may be the precise nature of the circumstances under which such animal matter is *prevented* from decomposition of the normal kind, but, instead, passes into bituminoids, is a question which must be left for students of organic chemistry to answer, if the answer is to be to the satisfaction of geologists.

Whatever causes may have combined to bring about a mingling of half-decomposed animal matter with the mud and fine clay whose thin films were giving rise to the formation of oil shales, it is quite certain that they must have been of a very exceptional nature; for shales containing so large a proportion of hydrocarbon as to be of *commercial* value occur only in two

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British deposits, to wit, the lower half of the Lower Carboniferous rocks, within a small area in the Lowlands of Scotland, and a thin band in the Upper Jurassic Rocks — in the Kimeridge Clay of Dorset. In all other British formations, and even in these mentioned beyond the area named, decomposition of animal matter (which, of course, must have occurred in abundance on innumerable horizons) appears to have proceeded so far in every case as to leave not a trace of any bituminoids behind.

With organic matter of vegetable origin, the case, of course, is far different. But how this vegetable matter could at one point contribute to the formation of sandstones, as it does at Craigleith and at Hailes Quarries, near Edinburgh; at another point give rise to coal seams; and at a third, all within the same geological period, give rise to oil shales, is again a question for a reply to which we must once more turn to the Chemist.

My friend Dr Heddle, himself a chemist of renown, and at the same time one of our foremost pioneers in much that relates to Scottish geology, warns me at this point against the danger of venturing into a domain unfamiliar to me, but within which he himself is so much at home. Geologists, he says, with much truth, have often committed serious errors in wandering from their own territory into that of their neighbours, and especially into that claimed by the chemists. He is right, I feel sure; but when he and his fellow-workers have been repeatedly invited to take up questions of this kind, they have generally declined to do so, without giving any reason. What can geologists do, therefore, but take up the question themselves, and reason out an answer to it by means of observations made from their side of the border? In other words, it appears to me that we may get some kind of suggestion as to how at least a few of these facts have arisen from a careful study of the facts themselves. This I will now attempt to do.

We must begin by reviewing the chief points of importance connected with the mode of occurrence of hydrocarbons and their commoner associated substances in rocks in process of formation to-day, and then go on to consider those formed in past ages. (1) In regard to their geographical distribution—this may be said to be world-wide. (2) The age of the strata from which these compounds are obtained extends from Recent times back to the Older Palæozoic Period. (3) They occur equally in association with, and far removed from, rocks of eruptive origin. (4) They are not confined to strata which have undergone mechanical disturbance, but occur almost as frequently amongst rocks which show no sign of any such earth-movements. (5) In a great

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majority of cases they are associated with strata which there is other reason for regarding as having been formed in closed bodies of water, under sub-humid, or at the most, sub-arid, climatal conditions. (6) And, lastly, they are very generally, though not invariably, associated with rock salt, gypsum, and other deposits commonly associated with these mineral substances.

In regard to the deposits of rock salt and gypsum, it is generally recognised at the present day that these must be looked upon as deposits from precipitation, which have been thrown down in closed bodies of inland water, in which the water brought into the lakes by their feeders is mainly dissipated by evaporation. In such bodies of inland water the tributary streams transfer from the air and the land considerable quantities of various substances, which, carried down in solution, are eventually deposited in the solid form as the water evaporates. Of these substances, one we are at present concerned with is rock-salt (which, driven up from the sea during storms, afterwards forms the nuclei of rain drops; and is thus again transported seawards, under *normal* conditions of drainage). The other is gypsum, which is mainly derived—perhaps directly—from the land. Along with these substances transported in solution there often occurs more or less organic matter, amongst which vegetable remains predominate. To gain a clear idea regarding the kind of conditions I have in view, I would ask the reader to endeavour to realise what is occurring now in the lower part of the Valley of the Jordan, and in the terminus of that valley, the Dead Sea. This is an area of inland drainage where the conditions as regard rainfall are sub-humid, or, at the most, sub-arid. The district drained is mostly calcareous, therefore the Jordan carries down much lime in solution, partly as carbonate, partly as sulphate. Rain carries down Chloride of Sodium and Chloride of Magnesium (both of them being, I believe, mainly derived from sea-spray), mostly in the form of the nuclei of raindrops. The Jordan sweeps down considerable quantities of vegetable matter—for the Jordan Valley itself is well-wooded. As the whole of the water carried in by the Jordan escapes by evaporation, the dissolved substances are either left in solution, or else are precipitated. So we have a strong solution containing Chlorides of both Sodium and Magnesium, as well as other chlorides. With these the river carries from the land solutions of Sulphate of Lime, together with organic matter, chiefly of vegetable origin, in larger or smaller quantities. Bitumen occurs in considerable quantities, apparently formed in thin sheets at the *bottom* of the Dead Sea, whence, after earthquakes, it is dislocated, and eventually rises to the surface, and floats

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ashore, where for a long time it formed the chief source of supply of the bitumen used by the Ancients.

If we study the lakes occurring in the inland drainage area of Central Asia, much the same facts come to light. Those which receive water supplies from regions where vegetation in some form or other occurs, all show deposits of rock-salt, gypsum, together with one or other of the bituminoids or hydrocarbons, solid or liquid.

If we study the Pitch Lake of Trinidad, there again we find this marked association of bituminoids and sulphates. (In this case the explanation of the association is, it seems to me, just the same as I would apply to the other cases, even though at first sight there may appear to be important differences.) The same is true in Sicily.

If now, instead of considering what this explanation may be, we pass on to consider what one may term the fossil examples of the same kind, facts and associations of precisely the same nature come to light. Whether we study the Miocene lacustrine phenomena of Central France, the deposits of Jurassic age on the Continent or in Britain, or the Older Palæozoic rocks, where these bituminoids in one or other of their many forms occur, in nearly all cases do we find the same association of rock salt and gypsum (or, if not these, yet clear evidence of exceptional conditions of deposit) with the occurrence of bituminoids. In the Caithness Flags we have an excellent example of one of the many manifestations of the same nature. This particular case the reader will find discussed in some detail in a paper specially dealing with this subject, which is published in the Proc. Roy. Physical Society, 1897.

In almost every case where the nature of the rocks suggests formation in lagoons (*i.e.*, bodies of sea-water temporarily cut off from the sea, and containing dissolved salts more or less concentrated by evaporation), or in areas of inland drainage, do we find the association of sun-cracked surfaces, pseudomorphs of rock-salt, with deposits of dolomite, gypsum, and one or other of the bituminoids. Not to go far afield for an example which does not pertain to the Oil Shale Series, we have it in the Sandstones of Salisbury Crags, in which the abundant occurrence of sun-cracked surfaces, the parti-coloured sandstones (whose colouring matter consists of ferric oxide, ferrous silicate, glauconite, and ferric hydrate), the calcareous breccias due to broken up crusts of precipitated carbonate of lime and dolomite, pseudomorphs of rock-salt, and other phenomena of the same general nature, we still find traces of bituminous matter.

This marked association, so often referred to here, seems to suggest what is the most likely explanation—or one, at any

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rate, which, as an hypothesis, may be tested by applying it to new cases as they arise. This is based primarily upon the fact, long known to chemists, that macerating organic matter, especially that of vegetable origin, and water containing weak solutions of sulphate of lime, bring about reciprocal reactions upon each other. The decomposing organic matter robs the sulphate of a part of its oxygen, which goes to form CO, whereupon the remaining sulphide readily passes further into the condition of carbonate, which may be precipitated, and in that form be either diffused through the strata forming, or may segregate into nodular masses. This is the origin of the Cornstones of the Upper Old Red, which mark the reactions consequent upon the arrival in the Old Red Lakes of remains of the earliest of the Carboniferous vegetation. It was this which gave rise to the very remarkable limestone of Burdiehouse, which consists of alternations of thin laminæ of oil shales, more or less calcareous in character, with equally thin laminæ of chemically-precipitated carbonate of lime, much of which is in the form of small pellets, not unlike the oolite granules now forming in the Great Salt Lake of Utah. It is also the origin of the material which, subsequently broken up, forms the calcareous breccias of the Salisbury Crag Sandstones. The dolomite and limestone bands and nodules in the Caithness flags, and the bituminoids associated therewith, have originated in the same manner. (See the paper above referred to, and also Geol. Mag., July 1889, p. 314; and Proc. Geol. Assoc. (Excursion to North-West Cumberland), 1889, p. 51.)

The reciprocal action lies in the fact that ligneous matter, and especially the looser vascular tissues of the lower forms of plant life, in the presence of solutions of sulphates in water, tends to dissolve, and to be converted into oily or gummy compounds. It is this cause, I have long believed and taught, which tends to obliterate the structure in so much of the vegetable matter that forms coal.[1] The vascular tissues so dissolved form the cherry coal, the vascular tissues which have been simply macerated form the cannel layers, while the ligneous matter forms the "mother of coal." Innumerable alternations of these may be found in some Scottish coals within the thickness of a few inches. (This view is held on the assumption that coal is of subaqueous origin, formed in deltas, and not on the land.) It is this same cause that makes the muds and clays of many deltas so highly carbonaceous, as is referred to at some length by Credner, in his article on Deltas in "Petermann's Mittheilungen," xii. No. 63, p. 16 (1878).

At present we have no means of judging what is the exact

[1] See the writer's paper on the Origin of Coal, quoted above.

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nature of the reactions now specially under consideration; but that it does actually take place no one who will carefully consider the facts can reasonably doubt. I have been led to conclude, from the study of a large body of facts, that the results are dependent chiefly upon the proportion which the quantity of sulphate in solution bears to that of the vegetable matter acted upon. Where the solutions are strong, and the quantity of vegetable matter relatively small, I should expect that the change proceeds so far as to dissolve the whole, at least of the vascular tissues, of the vegetable matter in question, to a kind of slime, in which form it would be readily mingled with, or diffused amongst, strata forming at the time. The bark of the lepidodendroids and other carboniferous vegetation appears to have been able to resist these solvent actions to a large extent. In the case of the Burdiehouse Limestone, for example, there is evidence of repeated alternations of carbonate of lime, in the form of small pellets (whose precipitation is due to the breaking up of the sulphate of lime by decomposing vegetable matter) and layers of more or less bituminous marl. I should suppose that this limestone was found in a lagoon, or perhaps in a series of lagoons, in which the water became concentrated, sometimes to a greater, sometimes to a lesser, extent; and that at intervals the quantity of vegetable matter was only just sufficient to bring about precipitation of the matters in solution; at other times it was in excess, and the vascular tissues of the plants, being dissolved by the solutions of the sulphates, passed into the mucilaginous condition, and in this form was diffused through, or became interstratified with, the chemically-formed limestone.

If this case stood alone such an hypothesis would perhaps hardly be needed; but that is by no means the case. If we adopt this explanation of the origin of the bituminoids as a working hypothesis we can readily perceive what is the source of the bitumen of Judæa—it simply represents the vegetable matter transported by the Jordan into the Dead Sea, and there dissolved in consequence of prolonged maceration in water containing considerable quantities of sulphates in solution.

The Pitch of Trinidad also appears to be due to the action of solutions of sulphates, which have risen through, and have bituminised, a subterranean bed of peat.

The bitumens of Sicily are produced in essentially the same manner, by the uprise of solutions of sulphates through deposits of carbonaceous matter.

Lastly, as regards the oil shales of the Lothians, I hold that they, too, were formed in lagoons of the old Carboniferous delta. It is quite possible that in many cases these may have been

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formed in connection with the Carboniferous volcanoes—though the connection is by no means a necessary one. Into these lagoons (in which sea water, or even river water, was undergoing evaporation, and in which the dissolved salts were gradually concentrated) were swept from time to time quantities of the same vegetation which elsewhere was being carried seaward from the land to form coal seams. Coming into contact with water containing dissolved sulphates, much of the vascular tissues of the vegetable matter underwent solution, and was eventually converted into mucilage, in which form it was diffused throughout the beds of laminated clay and mud then in process of formation. As the proportion between the saline and other constituents dissolved in the water, on the one hand, and the vegetable matter swept into it, on the other, varied to an almost infinite extent, corresponding variations in the character of the shales were exactly what might be expected.

The reciprocal reactions between the sulphate of lime and the vegetable matter gave rise to the precipitation of bands of impure and often ferruginous or dolomitic limestone, and of nodular masses of the same. Some of these enclosed more or less of the bituminous compounds, which were in consequence left sometimes as mineral pitch, sometimes even as anthracite, in the septal cracks formed in these nodules. This explanation readily accounts for the passage of the oil shales into shales of the ordinary type in one direction, or into cannel or even into blackband in the other, and also for their association with septarian nodules of clay ironstone.

Summary.—The general conclusion to be drawn from these considerations is that, while some hydrocarbons are undoubtedly produced by purely inorganic action (*e.g.*, the anthracite of the Calton Hill, &c.) and some by process of distillation, other hydrocarbons allied to the paraffines and bituminoids are due to organico-chemical agency. The hydro-carbonaceous matter of one set of these may represent organic matter of animal origin, which has been preserved from putrefaction and decomposition by some antiseptic solutions, whose nature is at present unknown. Others, and these the majority, it is here suggested, may be due to vegetable matter being swept into closed bodies of water containing a higher percentage than usual of sulphates in solution, which sulphates have converted the vascular tissues of the vegetable matter into mucilaginous compounds. These have been incorporated, as fast as they were formed, with the mineral sediments in process of formation at the bottom of the lakes or lagoons, and have thus given rise to beds of oil shales.

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XX.—*Obituary Notice of Hugh Miller.* By J. HORNE, H.M. Geological Survey of Scotland. (Plate IV.).

(Read 19th March 1896).

THE obituary of January contained the announcement of the death of Hugh Miller, younger and only surviving son of the illustrious geologist, whose name is a household word wherever the English language is spoken. When the history of the progress of Scottish geology comes to be written, his distinguished father will rank as one of the great popular exponents of the science in the middle of this century. The son devoted his time and talents to the pursuit of the science which the genius of the father surrounded with a halo of romance. It is due to the memory of our former colleague and fellow of this Society that we should recall some of the salient features of the work which he has left behind. Though his record has been suddenly broken, it was his wish, had he been spared to enjoy longer life and more robust health, to have developed some of those investigations in which he took part.

Our late colleague was born in Edinburgh on 15th July 1850, an event to which special reference is made by his father in a private note. The author of his father's biography has deemed this reference worth printing on account of the autobiographic touch respecting the father's birth, and the characteristically mournful reflection which follows. Hugh Miller wrote that his son Hugh, "in his introduction into the world had a sore struggle for life, and in pugilists' phrase, but with a deeper meaning than theirs, was for about five minutes 'deaf to time.' Accidents can scarce be hereditary, but my mother has told me that when making my *debut* I refused to breathe for a still longer period. Were all the future known to the little *entrants*, such refusals would, I dare say, be more common than they are, and more doggedly persisted in." He received his scientific education at the Royal School of Mines, to which he was nominated by Sir Roderick Murchison, on account of his father's important contributions to the science of geology.

Joining the staff of the Geological Survey of England and Wales on 26th May 1874, Mr Miller was engaged for ten years in mapping some of the Carboniferous tracts of the English border, under the supervision of Mr H. H. Howell, the present Director of the Geological Survey of Great Britain. The results

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James v. Tay

Hugh Miller

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of his work subsequently appeared in the official publications of the Survey. His memoir on "The Geology of the Country around Otterburn and Elsdon," published in 1887, is an illustration of his careful and painstaking method of exhausting the evidence within the area assigned to him. One of the features of this memoir is the frank acknowledgment of the work done by George Tate of Alnwick, who, between 1849 and 1868, had laid the foundations of the classification of the Carboniferous Limestone series on the south side of the border. He shows that Tate's classification into Tuedian, Carbonaceous, and Calcareous groups applies to the entire Northumbrian type of the Carboniferous Limestone, including Northumberland, East Cumberland, and Eskdale and Liddisdale in Scotland. These are the main divisions adopted in the memoir, the subordinate members having been named by the officers of the Geological Survey. Equally noteworthy is his method of stating the evidence in proof of the transport of land-ice from Dumfriesshire and Galloway across Northumberland, and his sketch of the physical history of the district and the development of its configuration. This official memoir is the most valuable contribution which Hugh Miller made to the science. His researches in the north of England led to a paper on "Tynedale Escarpments," their pre-glacial, glacial, and post-glacial features, which appeared in the Natural History Transactions of Northumberland, Durham, and Newcastle-on-Tyne, 1880. After reviewing the various theories of the formation of escarpments, he proceeded to show how the one propounded by Hutton, which attributed these features to atmospheric waste, adequately accounts for the phenomena. It has been eloquently advocated by Playfair, by Ramsay, by A. Geikie: it has been applied by Foster and Topley to the escarpments of the Weald, and by Whitaker to the Chalk and Tertiary escarpments. Referring to the effects of the Glacial period on Tynedale escarpments, Mr Miller states that all the facts he had been able to gather tend to show that these features, when fully developed both in "Crag" and "Tail," have suffered but little from Glaciation, but upon the terrace-form sculpturing of the low grounds it told heavily. Terraces consist of little more than escarpment fronts, and as the fronts have been rounded over, this has often meant obliteration to the terraces.

In 1881 he contributed to the Transactions of the Inverness Field Club a paper on "Coventina's Well on the Roman Wall of Northumberland," in which he gives a graphic description of that massive rampart, with its camps, castles, and watch-towers, regarding it as a monumental testimony to the bravery of the stubborn Caledonians and other tribes whom it was built to

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hold in check. Mr Miller described the remains of the camp *Procolitia*, about four miles west of where the wall crosses the river North Tyne, on one side of which occurred a well dedicated to an unknown goddess, Coventina. Here were found thousands of Roman coins, altars to the goddess, pottery, busts in bronze, and other interesting relics. He states various theories that had been advanced to account for this strange deposit, and came to the conclusion that this ancient spring was regarded by the Romans as a water goddess, to whom homage was paid by throwing in offerings, more or less valuable, according to the means and devotion of the worshipper.

On the completion of the Geological Map of England and Wales, Mr Miller was transferred to the Scottish Branch of the Survey in 1884, and from Cromarty, as a centre, he mapped the Old Red Sandstone along the northern border of the Moray Firth. It was at first a source of great gratification to him that he was entrusted with the survey of the area rendered classic by the descriptions of his father. While Ichthyology has made rapid advances since the appearance of "The Old Red Sandstone" in 1841, and while much light has been thrown on the zonal distribution of fossil fishes in this formation by the recent researches of Dr Traquair, it was a pleasure to him to bear testimony to the general accuracy of his father's observations on the structure of the district round Cromarty.

In 1885 he contributed a brief note to the Inverness Field Club on "The Sutors of Cromarty—a chapter on Pre-glacial Geology," in which he referred to the origin of the magnificent gateway that opens through the side of the precipitous wall of the Black Isle, and forms the entrance to the Cromarty Firth. Adopting the view of Sir A. Geikie, that it had been the work of running water, Mr Miller proceeded to show that the denudation had been slowly accomplished by means of the rains, rivers, frosts, and chemical agencies of the Tertiary period. The Sutor gateway, he stated, is not a recent breach of the sea, nor yet the work of the great ice-age, but a chasm formed by running water during the Tertiary age. He believed that the stream that cut this gateway was the river Conon, which drained the interior of the Ross-shire Highlands, and ploughed its way through the sandstone strata, which then spread to a much greater thickness on the lower levels. The valley-track of the ancient river Conon extended outside of the Sutors, the plain-tract probably lying along what is now the Moray Firth.

During his holidays in successive seasons Mr Miller visited Norway, for the purpose of studying the phenomena associated with those conspicuous terraces, the origin of which has given rise to much discussion among Scandinavian geologists. A

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very brief record of the results of this work was communicated to the Geological Section of the British Association at Aberdeen in 1885, entitled, "Some results of a detailed survey of the Old coast-lines near Trondhjem, Norway." I believe that he originally intended to publish these results in greater detail, but, so far as I know, the abstract in the Report of the British Association is the only summary of his investigations. Some of his general conclusions are as follows:—(1) These terraces are all post-glacial, that is, formed subsequent to the rock glaciation of the district. This is confirmed by the condition of the high coast cliff, which has been cut in ice-bound rock, but is not itself glaciated. It appears, however, from the fauna of the raised shell banks of the country (as worked out by Sars and Kjerulf), in which recent shells do not rise above 380 feet, that the seas of the upper levels were still glacial; and though the Trondhjem Fjord was free from land ice, other deeper fjords and higher coasts may still have had glaciers entering the sea, and producing the glaciated rock terraces described elsewhere by Sexe. All the evidence obtained discountenances Sexe's view that these rock terraces were cut out by glaciers, as well as Carl Petersen's, that they were rasped out by floating ice coasting the shores. On the clay terraces coast-ice has left no more sign of its presence than the winter freezing of our British rivers leaves upon our river terraces. (2) If the country was raised by a succession of elevatory jerks, as supposed by most geologists from Keilhau downwards, most of these would seem to have been small—much smaller than is supposed by Kjerulf. (3) The preservation or excision of the terraces thus seems to depend as much upon local circumstances—exposure to storms, resistance of coast line, etc.—as upon anything else.

To the Proceedings of the Royal Physical Society Mr Miller contributed two papers—one on "River-terracing: its Methods and Results"; another "On Boulder Glaciation." In the latter he called attention to the presence of fluxion structures in boulder-clay, due to the differential movement of the materials.

In the British Association Report for 1887 there appeared, from Mr Miller's pen, a brief abstract of a paper "On a Comparative Study of the Till or lower Boulder-clay in several of the glaciated countries of Europe—Britain, Scandinavia, Germany, Switzerland, and the Pyrenees." The sections of foreign boulder-clay examined by the author occur chiefly in the neighbourhood of the Trondhjem Fjord in Norway, at Berlin and Leipzic in Germany, near the Lake of Geneva in Switzerland, and in the valleys of the Pyrenees directly south from Pau in Southern France. In all the places mentioned (more doubtfully at Berlin and Leipsic) it bears the unmistakable character of a

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ground-moraine formed underneath glacier ice. He found the glaciation of boulders *in situ* to be a crucial distinction, having readily detected "the striated pavements" in the Tills of all the districts above mentioned, except Leipzic and Berlin, where the boulder-clays resemble the upper boulder-clay of the eastern sea-board of England and Scotland.

While vice-president of this Society, Mr Miller gave an address on "Landscape Geology," which attracted considerable notice at the time. The chief object of this address, which was characterised by much of his father's literary grace and imaginative force, was to ask the question whether geology has not at least the same claim to the attention of the landscape painter as human anatomy by general usage, if not by general consent, has to that of the sculptor. The following passage fitly illustrates his style and method of viewing the question.

"There is, I am aware, one great school in art in modern days, for which it seems to be claimed that *it*, at least, has need of no help from science—whether of geology or any other. I refer to the impressionist school. In mountain-drawing, for instance, impressionism presents us with outline and form, height and mass and distance, shadows and mist and snow; and truly it might seem at first sight as if artists of that school have learned all that they need to know. We are told that they give us 'values,' not details. I do not insist on the fact—true, so far as it goes—that the snow-drifts are *shaped* by the form of the hollows, and the mist by that of the valley and the hillside. But it does seem to me strange if men should propose to attain the maximum of ideality through the minimum of knowledge. I am aware that genius delights to appear to set at naught all rules; but I have been accustomed to think that he who would give us the *im*pression without the detail has need most of all to gain the power of reading the *ex*pression; that you cannot idealise the thing you are ignorant of—succeeding at best (if the attempt be made) in putting something else in its place. So long as the artist is willing to restrict himself to the superficies of things, his eye for form and colour, for effects and combinations of effects, is, perhaps, enough to serve his turn; but the moment he endeavours to give us real expression of character, he cannot, surely, do without some knowledge. I plead even with him for some judicious study of the *erdkunde* in this sense.

"The great message of geology to the nineteenth century has already been delivered. Little more than fifty years ago the horizon of ordinary thinking men was bounded, as if by a wall, by a line drawn only six thousand years back in the past. The widening of that horizon to its true bounds was one of the

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greatest intellectual achievements of the century—perhaps of all time. No longer hemmed in by the wall of Mosaic chronology—part of that 'wall of ordinances' that was to be broken down—we can lift our eyes to a distance so extreme that we cannot in the dimness distinguish land from cloud, or sea from haze—the mind's eye losing itself, wondering, in the supreme firmament of God's eternity. I would fain have the painter, of whatever school he may be, more cognisant of that distance, as well as of much that lies nearer."

In the course of his official duties in Scotland, Mr Miller traced the Old Red Sandstone from the shores of the Moray Firth north-eastwards to Sutherland, where, in recent years, in conjunction with some of his colleagues, he has mapped some of the older Crystalline rocks. In the eastern part of this country the Crystalline schists are traversed by broad belts and veins of foliated granite, some of which seem to have been intruded, after the manner described by the French petrographer, Michel Levy, as *lit par lit* injections. From evidence obtained by him, he was led to believe that the structures in the granites and granitic gneisses are to a large extent imitation structures, due to the simulation of the form and structural features of the country rock (the Eastern schists) by granites, that by some means have crept into their place. He believed that the process by which this replacement has been effected has been, to a considerable extent, a development of crystalline matter among the granulitic materials of the pre-existing schists and quartzites. While prosecuting these researches at Lairg towards the close of 1895, he was prostrated with typhoid fever, which eventually led to the sudden termination of his career.

Before closing this brief sketch of Mr Miller's career, it is due to his memory to refer to his protracted sufferings from insomnia, which doubtless prevented him from overtaking work that he wished to accomplish. Be that as it may, all who knew him well will readily admit that behind his somewhat reserved temperament there beat a kindly heart, that cherished with affectionate reverence the memory of what was bravest and best in the life of his illustrious father.

The following is a list of Hugh Miller's writings:—

1880. Tynedale Escarpments, their Pre-glacial, Glacial, and Post-glacial Features. Nat. Hist. Trans. Northumberland, Durham, and Newcastle.

1881. Coventina's Well on the Roman Wall of Northumberland. Trans. Inverness Field Club.

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1883. River Terracing, its methods and their results. Proc. Roy. Phys. Soc. Edin., Vol. VII. p. 263.
1884. Article Northumberland. Physical description. Encyclopædia Britannica.
1884. On Boulder. Glaciation. Proc. Roy. Phys. Soc. Edin., Vol. VIII. p. 156.
1885. On the Geology of Silloth Dock. Proc. Roy. Phys. Soc. Edin., Vol. VIII. p. 338.
1885. The Sutors of Cromarty—a chapter in pre-glacial geology. Trans. Inverness Field Club.
1885. Some results of a detailed survey of the old coast lines near Trondhjem in Norway. Rep. Brit. Ass. Trans. Sect.
1886. On the Classification of the Carboniferous Limestone series. Northumberland Type. Rep. Brit. Ass. Trans. Sect., pp. 674-676, and Proc. Berw. Nat. Field Club.
1887. Memoir on the Geology of the Country round Otterburn and Elsdon, being explanation of Quarter Sheet, 108 S.E. (New series 8.)
1887. On a comparative study of the Till or Lower Boulder Clay in several of the glaciated countries of Europe, Britain, Scandinavia, Germany, Switzerland, and the Pyrenees. Rep. Brit. Ass. Trans. Sect.
1890. Landscape Geology: a plea for the study of Geology by Landscape-Painters. Anniversary Address as Vice-President of the Edin. Geol. Soc. Trans., Vol. VI. p. 129.
1890. On an Exhalation of Gases, under singular circumstances, from a Bog near Strathpeffer. Proc. Roy. Phys. Soc. Edin., Vol. X. p. 224.
1890. Notice of the Discovery of a Hoard of Silver Armlets and Coins at Tarbat. Proc. Soc. Antiq. Scot., Vol. XXIII. p. 314.
1890. Notice of Fragments of Two Sculptured Stones of Celtic workmanship found at Tarbat, Easter Ross. *Ibid.*, p. 435.
1896. Dream of Mr H., the Herbalist.

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XXI.—*On the Calton Hill and its relation to the Rocks in the Neighbourhood.* By JOHN HENDERSON, Vice-President.

(Read 20th February 1896.)

MY original intention was merely to bring before the notice of the Society a small section recently exposed in making a drain at the Low Calton, where the lowest portion of the traps of the Calton Hill was exposed, but seeing that a good deal of interest is centred on the hill at present owing to the making of the tunnel and other alterations going on in connection with the North British Railway, I have taken the liberty of calling attention to a few facts and theories connected with the hill.

The Calton Hill has not received so much attention from geologists as its larger neighbour, Arthur's Seat. This is no doubt due to the fact that its structure is much simpler than that complicated and puzzling series of rocks included in the Queen's Park. Still a number of well-known geologists have described its structure, and others have noted the minerals connected with it. Cunningham, in his "Geology of Midlothian," describes the rocks of the Calton Hill as a series of traptuffs and porphyries dipping to the east, and he seems to have considered them all intrusive. He also mentions certain sandstone strata dipping under the traps of the hill that were exposed in excavations made for the foundations of the Waterloo Bridge. He likewise calls attention to the stratified beds that overlie the strap at the eastern end of the hill. Maclaren, in his "Geology of Fife and the Lothians," gives a description along with a diagram of the Calton Hill, which, he explains, was mostly taken from a paper by a Mr Webster, a pupil of Professor Jamieson. He describes five beds of traptuffs and porphyry as forming the body of the hill, and shows them in the diagram dipping at a high angle to the east, and overlaid by a series of stratified beds, also dipping east. In the "Memoir of the Geological Survey for Midlothian" the Calton Hill is also described, but in a more detailed and perfect manner than had been done in any previous work. In it fifteen beds are enumerated as constituting the trap rocks of the hill. These are described as consisting of alternating beds of basalt, felstone, felspathic ash, porphyries, felsite porphyries, amygdaloidal felsites, stratified ash, &c. In this memoir a new and most important idea is brought out in connection with the geological history of the Calton Hill—viz., that it is a portion of the northern end of the volcanic rocks of Arthur's Seat brought into their present position in the Calton Hill by a fault. That a fault exists extending from the Castle along the south front of the Calton Hill and on towards the northern side of Arthur's Seat

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there can be little doubt. It was first suggested by Maclaren, as far as I am aware, to account for the differences in appearance and position of the rocks underlying the Old Town and the New. The strata that underlie the Old Town from the Castle to Holyrood consist of a series of brown, grey, and greenish shales and thin bedded sandstones, dipping east-north-east. These beds, if prolonged in their line, strike northward, and if not interrupted by a fault ought to be found underlying all the New Town, from the west end of Princes Street to the east end of the Calton Hill; but, instead, we find from the west end of Princes Street to St Andrew Street a very different set of rocks dipping west-north-west. From St Andrew Street eastward the strata gradually arch over and dip to the east, showing an anticlinal bend between St Andrew Street and the Calton Hill. This easterly dip continues through all the rocks of the Calton Hill, and as far east as Lochend. But although this easterly dip coincides with the dip of the rocks on the south side of the town, yet none of the beds are prolonged unbroken from the one side to the other. For instance, if the rocks of the Calton Hill extended in their line of strike southward, they ought to be found all the way down the Canongate; but instead of the traps of that hill we find only the sedimentary beds already mentioned as occurring between the Castle and Holyrood, all evidence going to prove the existence of a fault between the Old and New Town. The fault, as figured in Maclaren's diagram, extended in a straight line from the north side of the Castle rock along the south side of the Calton Hill. In the map of the geological survey the fault is extended eastward in a nearly straight line along the north side of the Queen's Park to Restalrig. This extension of the fault eastward is put in, I expect, to explain the theory of the Calton Hill being a portion of the north end of Arthur's Seat, as its present position, nearly a mile to the west, could only be accounted for by a downthrow of the rocks to the north with their easterly dip. Of late I think I have been able to prove this extension of the fault eastward, although not in the same line as laid down in the Survey Map. In the year 1887 I read a paper before this Society on sections exposed in making a drain through the Queen's Park at Holyrood. In that paper I mentioned that a portion of the excavations were carried through the parade-ground to the east of Holyrood Palace grounds, where beds of brown, blue, and greenish shale, dipping north-east, were exposed, and at the south-east corner of the Palace gardens beds of black shale were cut into containing abundance of entomostraca and fish remains of well-known carboniferous species. Those black shales were exposed to

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within a few feet of the whinstone of Salisbury Crags. The occurrence of black shales with the fish remains and entomostraca, so like those of the Wardie and Granton series, surprised me at the time, as, if continued in their line of strike southeastward, they ought to be found immediately on the back of the whinstone of the Crag, but we know that a very different set of beds overlie the Crag at this place. At the time the excavations were going on I watched to see if any portion of the whin of the Crag would be exposed, but where it ought to have been met with the workmen came upon a great depth of loose watery sand, indicating that the Crag was truncated here. The conclusion I arrived at was that a fault existed here which had brought down a higher set of sandstones and shales against the rocks of Arthur's Seat. Now the question is, are there two faults running in the same direction—viz., the one laid down on the Survey Map extending from the south face of the Calton Hill to Restalrig, and this one running along the north-west portion of Arthur Seat? I am inclined to think that the line of fault marked on the geological survey map is carried too far north, and that the great fault that has brought the rocks of the Calton Hill into their present position passes from the south face of that hill to the north end of Salisbury Crags, and in a north-easterly direction towards Restalrig, and I will give one or two reasons for thinking so. A number of years ago a bore was put down for water in Mr Robert Younger's brewery at Abbeyhill. The bore was made with the diamond drill, which brought up a nearly complete section of the rocks passed through in the shape of a core about 6 inches in diameter. The first beds passed through in this boring were of brown, grey, and greenish sandy shales, and one or two beds of black shale with entomostraca and fish remains nearly identical with those found in the section at the north end of Salisbury Crags. Now if the beds exposed in the Queen's Park were extended in their line of strike to the north-west they would pass over the ground where the bore was put down. And in that case the beds exposed in the parade ground would represent the beds that overlie the traps, conglomerates, and ash beds of the Calton Hill passed through in the Abbeyhill bore, but if the fault as marked in the Survey Map was correct this could not be, for the beds of the Arthur Seat series would extend northwards to the north side of Holyrood and join the Abbeyhill beds there. Other evidence that the fault passes to the south of Holyrood instead of the north is to be found in the Abbey Brewery at the foot of the South Back of Canongate. Evidence of a great fault has been met with in the mines and wells there that have been made for water, and at Brown's Close, near the foot of the Canongate,

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on the north side, porphyritic rock was exposed a number of years ago, which Rhind considered a portion of the beds of the Calton Hill. That the Calton Hill is a portion of the northern end of the volcanic rocks of Arthur's Seat, brought into their present position by a fault, I think there can be little doubt. To look at the position of the Calton Hill, lying about a mile west from the set of beds from which they are supposed to have been derived, we are apt to think it had got a great thrust to the west. But when the faulting took place the igneous and sedimentary beds of Arthur's Seat must have extended as far west, at least, as where the Calton Hill now stands, and having the same easterly dip we can see that a downthrow to the north and a denudation of the southern portion would bring the igneous rocks of the two hills into their present position. The extent of the fault might be roughly estimated by taking the dip 15°, and the distance nearly a mile; this would give a downthrow or upheaval in the fault at this place of about 1200 feet. Coming now to farther proofs of the origin of the Calton Hill, it was pointed out by Sir Archibald Geikie, who had done the work of the survey in this district when the memoir was published, that the lowest beds of the Calton Hill closely resembled the rock to the east of St Anthony's Chapel, known as St Anthony's Crag. I may say I have got a little farther proof of this in a section lately opened at the Low Calton. Here a portion of the lowest beds yet seen of the traps of the Hill was exposed. The rock is a remarkable looking basalt, containing cavities filled with crystals and other varieties of quartz, along with dogtooth spar and other forms of calcite and masses of jasper. And in examining the rock of St Anthony's Crag I found pieces of jasper in the rock of the same character as those found at the Low Calton, and I have not been able to find jasper in the same condition in any of the other beds either in Arthur's Seat or the Calton Hill. The other minerals found in the cutting at Low Calton I have also found in St Anthony's Crag but not in such abundance. In making the new road for the north back of the Canongate a fine section of nearly all the lowest beds of the Calton Hill is exposed, showing a series of basalts, traptuffs, felsites, and felsite porphyries, but to separate the beds of the hill in detail at this place I would not attempt. They get more porphyritic as they rise in the series, and the highest become both amygdaloidal and conglomeratic. This was proved by the deepest part of the bore in the brewery at Abbeyhill, details of which I gave in a paper before the Society some years ago. The lowest bed of trap yet observed is the one I have already mentioned as exposed in the cutting for the drain at the Low Calton, and at the south end of the

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cutting brown shales were exposed dipping in towards the trap, but whether they passed under the trap or not I could not say. If the beds of the Calton Hill are a portion of the rocks of Arthur Seat from St Anthony's Chapel eastward, then the rocks that underlie those beds and extend westward in Arthur's Seat ought to be found to the west of the Calton Hill. These would include the traps that underlie St Anthony's Chapel, and the rock known as the Longrow and the Bog Craig, and all the sedimentary bed that lie between these and Salisbury Crags, along with that Crag, and in fact all the beds that underlie the Old Town as far west as the Castle. Now to the west of the Calton Hill we find a very different set of beds. Cunningham, in his "Geology of the Lothians," mentions sandstones being exposed in excavating for the foundations of the Waterloo Bridge as apparently dipping under the trap, and thick-bedded sandstones are at present exposed, lying nearly horizontal at the north end of the North Bridge. From there, westward, the beds gradually take a westerly and north-westerly dip throughout all the New Town, showing that an anticline bend exists between the Calton and St Andrew Square. Such being the case, if no other fault or interruption occurs, we might expect that all the beds of the Calton Hill would be repeated to the west of St Andrew Square, but no such beds occur there. The beds that underlie the New Town consist of brown, grey, and black shales with thick and thin bedded grey sandstones, mostly belonging to the Wardie and Granton series. Throughout these several vertical dykes of intrusive greenstone occur, but no bedded contemporaneous traps like those of the Calton Hill and Arthur Seat exist in the district. Now we have a different set of rocks and a different set of conditions lying to the west of the Calton Hill than that lying to the west of Arthur Seat, and we can only attempt to explain this by introducing another fault lying somewhere between the east end of Princes Street and the west face of the Calton Hill running in a northerly direction, and with a downthrow to the west, bringing the lower beds of the Granton series to a level with the traps of the Calton Hill or middle portion of the beds of Arthur Seat. In studying the various phenomena we cannot help wondering and speculating on the enormous changes the rocks of the neighbourhood have been subjected to since the early part of the lower carboniferous period. First we have that extensive series of reddish sandstones, grits, and conglomerates with brown, grey, and greenish shales that extend all over the south side of the town 2000 or 3000 feet in vertical thickness. Then these were interrupted by intrusions and outflows of igneous rocks only, portions of which can now be seen in Arthur Seat and the Calton Hill. The contemporaneous volcanic rocks

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of these hills I consider were mostly produced under submarine conditions, judging from the number of sedimentary beds of ashy matter found among them, notably the bed of stratified ash, with both fish and plant remains, seen under the basalt of St. Anthony's Chapel. Then we can trace a gradual dying out of these volcanic conditions, as is shown by the boring operations in the brewery at Abbeyhill, where the felsites, felspathic ash, porphyries, and conglomerates gradually get overlaid by finer sandstones and shales of the Granton and Wardie series. It must have been after all the lower carboniferous rocks had been deposited, and even after all the carboniferous limestone and edgecoal series of the neighbourhood had been laid down, that the great faulting took place that threw up the Pentland ridge and the rocks of Arthur Seat, or threw down the rocks on each side of that ridge, as the two great faults that flank the Pentlands on each side show. One fault, extending from the Carlops to the sea at Portobello, has brought down the carboniferous limestones of Gilmerton against the lowest beds of the lower carboniferous at Craigmillar and Liberton, and must have had a downthrow in that district of 8000 or 9000 feet, as it has cut off all the lower carboniferous rocks, and all the carboniferous rocks to the south-east of this fault are tilted at a very high angle along the line of fault with an easterly dip. The fault on the north-west side can be traced from Currie down the Water of Leith to Colinton, and from there to the west side of Craiglockhart Hill and on to the north side of the Castle rock and south side of the Calton Hill, and from there to the north-west side of Arthur Seat. Though not so great or so extensive as the one that flanks the Pentlands on their south-east side, it is still a considerable fault. Its greatest downthrow, as far as I can make out, is somewhere about Craiglockhart. At the cutting made for the Suburban Railway to the north of that hill, shales belonging to the upper beds of the Granton series can be seen lying at a very high angle against the red sandstones of the lowest beds of the lower carboniferous, showing a downthrow here of at least 3000 feet. A finer example of a fault seen in open section could not easily be found. The effect of these faults, at whatever period they took place, would be to elevate a great ridge of land between the two great faults, including the Pentland Hills and all the district lying between there and Arthur Seat, also that hill and the district lying further north several thousands of feet above the land on each side of it, and bending the strata into synclines and anticlines. After the faultings, bending, and tilting of the strata had taken place, enormous denudation set in, reducing all those great inequalities to the condition we now find the district in.

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XXII.—*On the Relation of Valley Moraines to Underlying Strata in Coulin Forest, Ross-shire.* By J. HORNE, H.M. Geological Survey of Scotland, President. By permission of the Director-General.

(Read 20th February 1896.)

IN the course of my official work in Coulin Forest to the south of Loch Maree, I observed rather an interesting feature, bearing on the relation of valley moraines to the underlying strata. The evidence there obtained seems to lead to the conclusion that the nature of the morainic materials varies according to the character of the rocks over which the glaciers moved. Glacialists have long been familiar with the fact, that, in the case of boulder-clay, which is regarded by most geologists as a product of land-ice, there is a constant relation between the stones and matrix of that deposit and the rocky floor traversed by the ice sheet. As a rule we find that the colour and nature of the matrix, as well as the lithological characters of the included stones, are mainly determined by the local rock-formation. There is doubtless a small percentage of the blocks which have been transported from a distance, but the majority of them are of local origin. These phenomena are just what might be expected on theoretical grounds, if we suppose that boulder-clay is a true ground-moraine which has accumulated underneath the ice and has been driven forwards by the pressure of the advancing mass.

When, however, we turn to surface moraines, lateral and terminal, the phenomena are somewhat different. Those morainic deposits which have been borne downwards on the surface of a glacier have been mainly influenced by the character of the rock-formations on the sides of the valley. It follows also from the method of transport on the surface of a glacier that morainic materials do not show the same evidence of having been subjected to a process of abrasion as the constituents of boulder-clay. Striated stones are rare, and the moraines consist of loose débris and sand with sub-angular stones.

In the case of the moraines in a particular area in Coulin Forest, my attention was at once arrested by the rapid change in the character of the included blocks after crossing boundary lines between different rock-formations. Before proceeding to describe some of the instances which came under my notice, brief references may be made to the physical features, geological structure, and glaciation of the region under review.

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That portion of the Coulin Forest to which I wish more particularly to refer lies from five to six miles to the SSW. of Kinlochewe. It is drained by the tributaries of the Coulin River, which flows northwards to Kinlochewe and thence to Loch Maree. One of the striking physical features of that region is Sgurr Dubh which rises to a height of 2566 feet, remarkable alike for its geological features and for the evidence of glaciation on the crest of the mountain. From this peak southwards to Ben Liath Beag there is an important water-shed above the 2000 feet level, the eastern slope of which is drained by Allt na Luib—a tributary of Loch Clare.

This area lies wholly within the region affected by the post-Cambrian terrestrial movements, and consists of sub-parallel belts of Torridon and Cambrian strata repeated by folds and reversed faults lying to the west of the great Thrust-plane that stretches southwards from Glen Logan by Coulin Lodge and Cnoc Daimh to Achnashellach. By means of stream sections and rock exposures on the plateau to the east of the foregoing water-shed, it is possible to fix with precision the boundary lines between the Torridon and Cambrian strata.

Before the advent of the local glaciers that produced the moraines on the eastern slopes of the Coulin Forest, there is clear evidence for maintaining that even the loftiest peaks of that region were overflowed by the ice during the climax of glacial cold. Within a short distance of the cairn on the crest of Sgurr Dubh, at a height of about 2500 feet, striæ were observed pointing a few degrees north of west, and numerous instances were noted with a similar trend at an elevation of 2250 feet. In like manner along the water-shed, southwards to Ben Liath Beag, the ice markings point from WNW. to W., and in some instances on the plateau east of the water-shed fine cross-hatches may be noted indicating movements at successive periods; the older set trending W. 30°-35° N. and the newer set from E. 40° N. to N. 43° E. My colleague, Mr Hinxman, has found striæ at greater elevations in West Ross-shire than any recorded in the Coulin Forest.

In one of the streams in Coulin Forest—viz., the east branch of Allt na Luib, there are fine sections of true boulder clay underlying the later moraines. It consists of stiff, stony clay, with well striated stones, which, though resting on Cambrian strata, contains blocks of Eastern schists, thrust Lewisian gneiss, and displaced Torridon flags and sandstones. Indeed, the difference between the products of the earlier and later glaciations is very marked at that locality. The occurrence of boulder clay, however, is quite exceptional in the area under review. In general the moraines rest directly on the underlying rocks.

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Proceeding westwards to the west branch of Allt na Luib, the relation between the morainic materials and the underlying strata is admirably exposed. The hill slope is strewn with moraines, arranged in conical heaps and ridges, composed of loose débris and sand with sub-angular stones, produced by glaciers moving north-eastwards to Loch Clare. Several prominent structural lines cross this area in a north-east and south-west direction, marking the limits of the Torridon and Cambrian formations. In each case I observed that the included blocks in the moraine mounds vary according to the nature of the subjacent rocks. When the latter consist of Torridon sandstone, the morainic materials are composed chiefly of Torridon débris; and a similar relation is observable when the rocky floor is paved with Cambrian strata. These phenomena seem to me to point to the conclusion that the materials of these valley moraines have been derived in part from the underlying rock formations over which the local glaciers moved.

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XXIII.—*The Sands and Sandstones of Eastern Moray.* By Wm. Mackie, M.A., M.D. (Elgin).

(Read 19th March 1896.)[1]

The question that naturally rises in the mind of the wanderer among the sand-dunes of Culbin is—"Where did all the sand come from?" Many years ago, while viewing this far-spreading wilderness of pure sand, Sir Charles Lyell exclaimed, "What a Manufactory of Sandstone!"[2] Briefly to describe a method, by which we may hope to attempt an answer to the question of origin of such sands, and by implication also of the sandstones, which, by various processes and at various times, have been derived from them, and generally to review the results of the application of this method to the sands and sandstones of Eastern Moray, are the objects I have set before me in the present paper.

If we were to take a sample of the sand of Culbin and examine it under the microscope, with the view of determining its composition, we should find that out of 100 of its beautifully rounded particles about 78 per cent. were entirely composed of quartz, about 18 per cent. were felspar, and of the remaining 4 per cent. 1 per cent. would probably be a composite fragment of quartz and felspar; 1 a flake of mica, 1 a fragment of garnet, and the remaining 1 per cent would be represented by either a particle of magnetite or a chip of hornblende, tourmaline, zircon, or sphene. These latter minerals turn up so rarely, though all are present, that they may justly be called the accessory minerals of the sand.

In this analysis, what is likely to strike the observer as peculiar is the inordinate disproportion of the quartz to the felspar and other constituents of the sand. But the Culbin sand is not unique in this respect. Among the several hundred analyses of sands I have made by this method, I have found few examples, either among the sands or sandstones, with less than 60 per cent., and not a few of them show over 90 per cent. of quartz particles. I need not remind a scientific audience that sands and sandstones alike have been derived from previously existing rocks; that, if we could trace them far enough back,

[1] *Read before the Inverness Scientific Society and Field Club, 11th February* 1896.

[2] Dr Gordon, Transactions of Geological Society of Edinburgh, 1892, p. 243.

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no matter how many intermediate stages there may have been, we should find that all of them have been originally derived from the crystalline rocks. Around here[1] I doubt not we should probably trace most of their constituent particles back to the fundamental gneiss. Now gneiss contains felspar in quite as large proportion as quartz. It also, as you know, contains a considerable proportion of mica as an essential constituent. How, then, does the felspar get frittered down to the modest modicum of 18 per cent. and the mica down to 1 per cent.? Simply because the felspar is softer and more easily disintegrated, breaks down into finer dust than the quartz, and this, combined with its slightly lower specific gravity and the exceeding fineness of the ultimate particles into which it finally gets broken down, contributes to the facility with which it is separated and washed away from the quartz. As a few illustrations out of many I have come across of this natural tendency to the elimination of felspar as a constituent of sand, with continued attrition, I give the following:—

The sand of the River Spey at Cromdale was found to contain . . .	18	per cent.	felspar.
At Ballindalloch (*i.e.* going down the river) . .	16	„	„
At Blacksboat . . .	13	„	„
At Craigellachie . . .	15	„	„
[Here, however, reinforced by waste of Benrinnes granite,]			
At Orton again it had gone down to . . .	12	per cent.	felspar.
The sand of the River Findhorn above Dulsie Bridge again showed .	42	„	„
At Logie Bridge . . .	31	„	„
Between railway bridge at Forres and sea . .	21	„	„

So much for the action of running water. The action of the waves along the sea shore reduces the felspar still further. The average of the four determinations of the sands of the four principal rivers in the samples that have been taken nearest the sea gives 18 per cent. of felspar, while the average of several specimens of sea sand gives only 10 per cent. felspar. The action of the wind is also apparently an important factor in the elimination of felspar. The average of the Findhorn and Nairn River sands shows 24 per cent. This in the Culbin sands, which appears in large part to have been derived from

[1] Inverness.

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these, has gone down to 18 per cent., and still further east at Burghead it has gone still further down to 8 per cent.

From the continued action of these agencies then we may conclude the felspar gets reduced to the limited quantity we observe in the finished product.

Mica, which is almost always an integral part of the rock debris, which eventually gets transformed into sand, is also easily disposed of. Its flat, scaly condition, notwithstanding its slightly higher specific gravity, enables it to be easily buoyed up and floated away from the quartz by the agency of running water.

We have thus, it will be seen, to depend largely on the quartz particles to tell us the history of the sand of which they form a part. It sometimes happens, however, that the felspars that remain afford an important clue as to origin; less frequently the micas, though it must be admitted that even they sometimes yield confirmatory evidence; while, of the accessory minerals, being, as they often are, the heaviest, hardest, and, consequently, most resisting particles, it may be said that they are frequently of the very greatest service in guiding us to a correct conclusion.

For instance, to take the case of the felspars in the Culbin sands. Some of these conform to the pattern of the large felspars in Ardclach granite, in containing inside them minute oblong felspars, with clear borders and dark centres; while others are of a different pattern, seen in Kinsteary granite, and contain well-formed crystals of magnetite in their interiors. In the sand again and in both[1] granites we find flakes of mica, showing muscovite and biotite (white and black mica) in parallel intergrowth. These observations of themselves would go far towards warranting the inference of the derivation in part of these sands from the granites just mentioned; but when taken in conjunction with observations of a similar kind on the quartz particles, such conclusion becomes practically irresistible.

Then as regards the accessory minerals, if, for instance, we find a sample of sand containing—as we do in the case of the matrix of a L.O.R. conglomerate at Gollachy—10 per cent. of garnet we shall be well advised to look out for fragments of such schistose rocks as we know from previous experience that garnets are commonly found in, and there to be sure in abundance such fragments are.

If prisms of zircon showing it may be, as they very frequently do, very little rounding of their original outlines, are present in abundance in a sandstone, as they are in some of the very earliest

[1] Typically, however, in the Ardclach granite, but the same arrangement is frequent in the local gneisses.

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L.O.R. beds, we may also expect the presence of the debris of rocks in which zircons are known to occur; or, again, if in the sand of a stream [the Rothes Burn it happens to be, just before it joins the Spey] we find 8 per cent. of particles of magnetite and titaniferous iron, along with 7 per cent. of hornblende, and that these, are associated with fragments of triclinic felspar, we naturally look for, and expect to find somewhere in the course of the stream a considerable outcrop of diorite, of which rock we know the forementioned minerals to be essential constituents, and there to be sure the diorite is.

Sometimes, again, certain accidental circumstances connected with the size, shape, surface markings, or incrustations on the surfaces of the different particles of sand, may tell us something of their previous histories. As regards size, it will be manifest we need not look for the origin of quartz grains 1-20th (·05) of an inch or more in diameter among rocks where the unbroken, unworn grains of quartz in the rock *in situ* do not exceed 1-200 (·005) of an inch in diameter. This question of mere size is of itself sufficient to mark off many of the grains derived from gneiss and granite from those derived from the younger schistose rocks. Again, if even the largest grains of a specimen—for the larger grains are all but invariably the more rounded—show little or no rounding of their outlines, we infer that they have not travelled far from their parent rock. If at the present day the most rounded sand particles we can find anywhere at the surface in this part of the country are the particles of the Culbin Sands (Fig. 3, pl. 19), which we know owe their rounding almost entirely to æolian agency, we shall not be far wrong if we conclude that the Elgin Reptiliferous Sandstones, of which the component particles are far more rounded still (Fig. 2, pl. 19), were largely accumulated under the influence of the same agency. Once more, if on the particles of a sand we find parallel surface-scratchings,—but they have to be carefully distinguished from parallel fissures and other structural lines in the grains,—we may infer with some certainty the operation of glacier ice. Or finally, if in the Culbin sand or any other surface sand we find grains sheathed in a clear casing of secondary quartz, or covered, it may be, with a dark envelope of red oxide of iron, we may infer derivation to that extent in the one case from a quartz-cemented, in the other from an iron-cemented, sandstone.

From these sources, it will be observed, the evidence regarding origin is at best negative. More frequently only what might be called snatches of the intervening histories of the various particles is all that is revealed. To learn something of their real origin we have to go deeper. When we come to look at our

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quartz grains with a moderately high power of the microscope—say ½ in. objective magnifying 100 diameters—nothing less being of much use for our purpose—we find that many of them contain inside them numerous little objects of various shapes and colours. Some of them are seen to have beautiful mathematical outlines, some of them to be of very irregular form. Many again are beautifully coloured, others are characterised by only inky blackness. Here, as elsewhere, the microscope reveals a new world, and opens up a whole vista of possibilities by which we may hope to trace the origin of the containing grains. What we see are inclusions or enclosures in the quartz. Some of these inclusions are crystals—often perfectly regular, rigidly mathematically outlined crystals of other minerals enclosed in the quartz. Others, again, are lacunæ—little lakes containing fluid. Some of these are completely filled, others only partially filled with this fluid. In the latter case a bubble of gas is to be seen along with the fluid. Sometimes, apparently, only gas is present in the little interspace, and then it appears to the eye of an almost inky blackness.

For our present purpose we divide these inclusions into three classes, and our quartz grains, in virtue of the kinds of inclusions they contain, into four classes—one class of quartz grains being characterised by the general absence of such inclusions.

I. Regular Inclusions, and the quartz grains containing them, are classified as regular-inclusioned grains.

II. Acicular or fine needle-like inclusions and the grains showing these as acicular-inclusioned.

III. Irregular inclusions, giving an irregular-inclusioned group.

IV. Grains without inclusions, or where inclusions of the irregular type are so small as practically to escape notice.

Shortly, then, we classify quartz grains, as regards inclusions, into Regular, Acicular, Irregular, None, for the sake of convenience, indicating the groups by the initial letters R, A, I, N.

Among the regular inclusions found in the quartz particles of the sandstones of the area under examination, of such as have been identified, I note the following minerals—quartz as an inclusion in quartz, chlorite, muscovite, biotite, rutile, apatite, zircon, garnet, magnetite, titaniferous iron. The list might probably be largely extended by observation directed to the point, but up to the present my interest has largely centred in the acicular group. Here the inclusions appear as fine dark lines running in all directions through the quartz grains. These needles do not appear to have been largely observed—at least the microscopic variety of them has not been largely observed by either mineralogists or petrologists. Mr Prior, one of the petrologists attached to the British Museum, had not seen them

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when I brought them under his notice some months ago; but sometime afterwards he wrote me to say he had since observed them in the quartz of several granitoid rocks. Strange enough, I discovered them, more than a dozen years ago now, in the very first microscopical section of a granite I ever cut. This happened to be a specimen of Aberdeen granite, in some varieties of which they exist literally in thousands.

The mineral character of the needles appears to be equally doubtful. Mr Prior sums up the opinions that have been given, but carefully avoids giving his own. You can easily see from the nature of the case that little more than an *opinion* could well be expected. Another variety of needle which also occurs as an inclusion in some of the quartz particles of these sandstones is easily identified as Sillimanite. These are perfectly colourless, occur in tufted or sheaf-like aggregates, the individual needles often showing a transverse cleavage which easily distinguishes them from the finer dark variety which has generally though not invariably been ascribed to rutile. Whatever the nature of the latter class there can be little doubt that they are very widely distributed. I have examined very few specimens of sand from which quartz grains containing them are entirely absent. With only a few exceptions, they have been present in all the specimens of sandstone examined, and with one exception I believe in all the surface sands yet analysed. They are present in some of the quartz particles of the Kentish Rag, in the south of England. They are present in the sea sands of various parts of the English coast, and in a specimen of sand from South Africa which I examined a few weeks ago they are also to be found.[1] In the quartz grains of a quartz diorite (Fig. A, plate 18) which is found *in situ* at Netherly, near Rothes, they exist in such abundance, and the individual needles are often so large, that it did not seem to be beyond the bounds of possibility to make at least a qualitative determination of their composition. After much trouble in separating the quartz grains from a rotten specimen of the rock, making certain that these grains were free from other inclusions, reducing them to as fine a state of mechanical division as possible, then separating the needle dust from the quartz in virtue of their assumed higher specific gravity by a fluid of high specific gravity—(borotungstate of cadmium), I at last obtained a minute quantity of dark needle dust, which on examination I am sorry to say gave only negative results. A borax bead was not coloured in the slightest degree by the total quantity separated, so that on the strength of this result we should exclude the presence of both iron and titanium. If the latter is

[1] I have lately observed these as well as the Sillimanite needles in the beautifully rounded grains of a sandstone pebble which was found included in the Torridon Sandstone near Kinlochewe.

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excluded, rutile is not present. However, I do not consider the result final, and must make another attempt before deciding. My first opinion regarding their mineral character was that they were probably fine, very fine prisms of apatite, but their association and grouping undoubtedly points to their being rutile.[1] There can be no doubt that small prisms of apatite do occur in many of the grains in question, and these, along with fine tourmalines, have from time to time, in all probability, found their way into and been classified in the acicular group.

The acicular group is capable of extensive subdivision into smaller groups in virtue of peculiar differences of arrangement of the needles within the quartz grains, and also in several cases by reason of their association with various inclusions of the regular type. It is this variety of arrangement and association that has enabled me to trace many of these sub-groups with more or less certainty back to their parent rocks.

Irregular inclusions need no particular description. They are almost always fluid lacunæ with or without gas bubbles. Various rocks are characterised by the presence or absence of gas bubbles in these fluid lacunæ. Thus the Benrinnes type of granite, both in the central mass and associated veins, shows bubbles in its irregular inclusions more frequently than the western granites of Ardclach and Kinsteary. When bubbles are present in the latter granites they are, relatively to the size of the containing lacunæ, almost always much smaller than the bubbles in the former granite. These differences are probably due to differences in the pressures under which these rock masses cooled. The quartz of Benrinnes granite again, it should be noted, frequently shows a tendency to arrangement of its irregular inclusions in parallel rows—sometimes in more than one direction in the same grain. In none of the specimens of the western granites examined has any such tendency been observed.

Now it may be stated as a fairly general law that acicular and irregular inclusions pre-eminently abound in the quartz of granite; that the regular group is to be found in various proportions, but always in relatively large numbers in the quartz of gneiss and the younger schistose rocks. A glance at the accompanying tables will make this evident at once. I have there evaluated the quartz of various rocks—that is to say, I have determined the *relative proportions of the various inclusions* in their quartz grains, when these quartz grains have been broken down to the size

[1] Since making this attempt at their chemical analysis I have made some determinations of the actual size of these needles in the diorite. I find they range from $\frac{1}{2500}$ to $\frac{1}{250}$ inch in length, and from $\frac{1}{12500}$ to $\frac{1}{2500}$ inch in breadth. To put it in another way: if a grain of quartz $\frac{1}{10}$ of an inch in diameter were magnified 1500 diameters—that is, up to 60 inches in diameter—the needles would come out like cedar-pencils and knitting needles of various degrees of fineness. Of course in some cases these needles are very much finer than those in the diorite.

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of ordinary sand grains, by observing and noting the character of the inclusions of the individual particles as they are successively brought into view in the field of the microscope. And here it may be well to state that where a grain contains two or more sets of inclusions, as not infrequently happens, the acicular have always taken precedence, and where they occur, though inclusions of other types have been present, the containing grain has been invariably registered "Acicular." Regular inclusions in the same manner have had precedence over the irregular variety. This it will be seen is simply a device to obviate cross classification.

Now the result of this quantification of the quartz of actual rocks has given the following results :—

The three eastern granites show an average of 65 per cent. of acicular grains and 13 per cent. of irregular grains—*i.e.*, 78 per cent. of the two combined. The two western granites of Ardclach and Kinsteary give an average of 30 acicular and 43 irregular, or 73 per cent. together, whereas the average of 8 schists and gneisses give an average of 1 acicular and 3 irregular, or only 4 per cent. in all. On the other hand, in the regular and negative[1] groups combined we have in the schists and gneisses 96 per cent., whereas the granites show only 22 per cent. and 27 per cent. of these respectively. These results establish the truth of the general law, but it should not be forgotten that exceptions do occur. I have found needles in the schists in three localities, but in each of these cases they have been found at the margin of an intrusive rock—in two cases at the edge of a granite vein, and in the other case at the margin of the Netherly diorite. These observations would go to show that in these situations the appearance of the needles has been due to contact metamorphism. In each of these cases, however, they have been associated with regular inclusions or grouped in such a way as would have left little doubt regarding their origin, should grains with the same characters have turned up in a sandstone.

But there is another important observation to be made before we leave this table. Compare the eastern and western granites. In the eastern the number of acicular grains largely predominate over the irregular—in fact in the proportion of 65 to 13. This I have called for the sake of convenience the "eastern granitic ratio." On the other hand, in the case of the western granites the irregular predominate over the acicular in the proportion of 43 to 30. This I have called the "western granitic ratio." Shortly the difference may be formulated thus :—

$$A > I :: 5 : 1 \text{ eastern granitic ratio.}$$
$$A < I :: 2 : 3 \text{ western } \quad ,,$$

[1] Must not be interpreted as meaning "Negative" inclusions, but simply the absence of inclusions generally.

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The significance of these differences will become apparent by and by.

The value of inclusions, as a means of tracing sand grains will, I think, be beginning to dawn on you, and we are now in a position to proceed with the analyses of actual specimens.

If it is a specimen of a recent sand that we are to examine, we have only to dry it and mount a good pinch of it in Canada Balsam. If it is a sandstone, we proceed to separate its component grains by gently crumbling it down if it is soft and friable between the fingers. In any case we use as little force as possible, never using such means or force as would be likely to break or otherwise destroy the characters of the individual grains. In fact with very hard quartz-cemented sandstones, it may be preferable to cut microscopical sections. We thus avoid the risk of breaking the grains. The sand derived from the breaking down of the sandstone is in all cases preferably boiled in hydrochloric acid to dissolve the oxide of iron, carbonate of lime, and other cementing substances, which would otherwise, in many cases, prevent us observing the inclusions altogether. The specimen is then washed several times by decantation, and there is little harm—rather an advantage, I should say—if the finer clayey debris is washed away with it, for it only serves to obscure our view of the sand grains proper, and is itself practically of little importance, so far as the purpose in hand is concerned. If, however, it is desirable to examine it, it may be collected in a separate vessel, and examined after it has settled. Substances soluble in acid must, of course, be looked for in a sample that has not been treated with acid. Boulder clays are washed by decantation, and only the sand particles proper retained for examination. These may or may not require preliminary treatment with acid. Our sample, after washing, is well dried, and a pinch of it mounted in Canada Balsam. And here I would observe parenthetically that the method described in books of temporary mounting in water is "no good at all." It may be all very well where it is simply the question of size or outline of the grains that is at issue. It is altogether useless where the inclusions are the main object of observation. We then proceed as before, recording the numbers of the grains containing the different classes of inclusions, in parallel columns, in the way already indicated, as they are successively brought into the field of the microscope. In this case, however, we also note the number of felspars, schist fragments, and accessory minerals in parallel columns.

Having evaluated a specimen of sand, it is often possible to assign, with some degree of probability, the proportions of the

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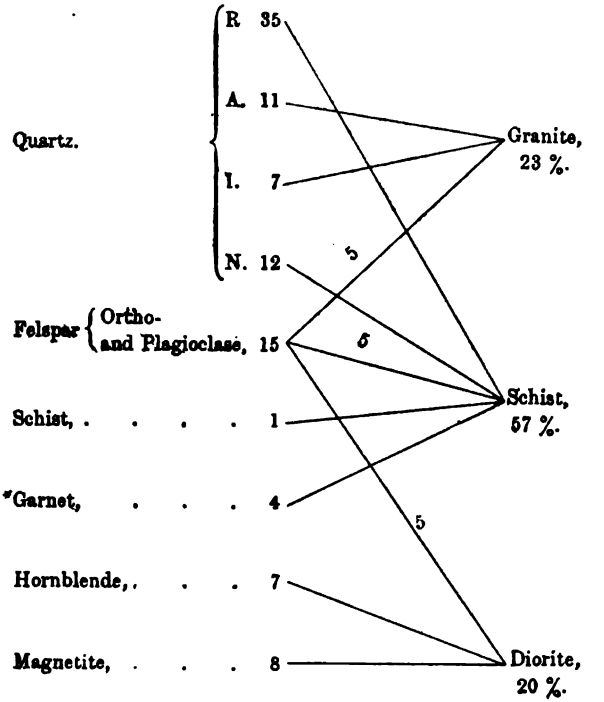
various rocks that have gone to make it up. Two examples are thus worked out—a recent sand and a sandstone—

SAND OF ROTHES BURN.



* Note.—Garnets occur mostly in the Pegmatite veins on this burn.

In the case of the Rothes Burn sand I have divided the felspars equally among the three groups, as some of the schists are felspar-bearing, and triclinic felspars having been noted as present in this sand, these would naturally fall to the diorite total. In the Gollachy conglomerate, also, some of the quartz acicular grains belong to the diorite, but the difference which these would make is of little consequence, since these evaluations are at best only the merest approximations.

But the chief interest of this method attaches, not so much to this, which might justly be called its quantitative aspect, as to what is really its qualitative side—I mean the actual tracing of the various groups of sand grains back to the particular

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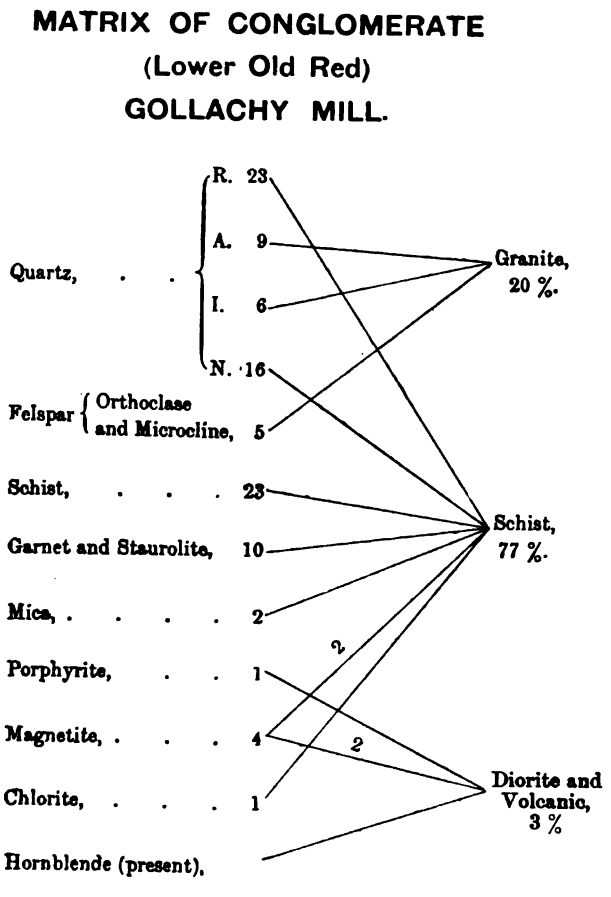
localities in the crystalline rocks from which they were originally derived. To do this, of course, we must come armed with microscopical sections of all the important rocks of the area, which, we have reason to believe, yielded the debris which has gone to make up the sandstones in question. In my own case, this process has gone on *pari passu* with the quantitative determinations of the various beds. Several groups have been



identified with all but absolute certainty. Regarding others, which may be traced to more than one locality, there is of course, at times, some doubt, while regarding a considerable residuum, I have not yet even a hint to go by in the matter of their identification. I will now briefly indicate the results, so far as the identification has yet gone:—

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Class of Grains.	Characters of Grains.	Where first Observed in Sandstones.
Quartz of Benrinnes Granite-Type.	As shown by the numbers of acicular grains predominating over the numbers of irregular. In large grains needles generally have a central position.	Dufftown, L.O.R.
„ Glengrant Granite.	1. Fine parallel cleavage of quartz, often in more than one direction in the same grain (Fig. B, plate 18).	Greens of Rothes, L.O.R.
	2. Turbid quartz with fine apatite prisms and very few rutile needles.	Auchinroath Burn, L.O.R.
„ Granite Vein Rothes Burn.	1. Rutile needles arranged parallel to margins of grain, and with or without violet hexagons.	Gollachy and Dipple, L.O.R.
	2. Polysynthetic quartz with or without needles, showing iron staining in the interstices both in native rock and in sandstones.	„
„ Granite Vein, Fiddich Bridge, Craigellachie.	Dark turbid quartz with parallel joint lines, and rutile needles nearly parallel to same.	Gollachy and Dipple, L.O.R.
„ Granite Vein, Spey Bridge, Craigellachie.	Large lacunæ with ragged edges, *small* zircons, apatites, and rutile needles [difficult to distinguish from quartz of Ardclach granite.]	Dipple, L.O.R.
„ Netherly Diorite.	Long, straight, well-developed needles radiating in all directions in immense numbers, through entire grain, which is frequently free from irregular inclusions. Apatite, magnetite, titaniferous iron, and zircon may be associated.	Auchinroath Burn, Dipple, and Gollachy, L.O.R.
„ Granite Vein intrusive in Diorite.	Large scattered needles with small pale-violet hexagonal plates or bacillary needles in immense numbers, the latter often in parallel lines.	Auchinroath, Dipple, and Gollachy, L.O.R.
„ Benrinnes Granite in various localities.	1. Variety with large needles and dark violet hexagons in rows.	Scaat Craig and Cornstone, New Elgin, U.O.R.
	2. Irregular inclusions in rows.	Dufftown, L.O.R.
„ Ardclach Granite.	With *large* zircons, apatites, and scattered needles; also ragged-edged lacunæ and irregular inclusions, mostly *without* bubbles [latter characteristic distinguishes from local varieties of Benrinnes granite.]	Scaat Craig, U.O.R.
„ Kinsteary Granite.	Peculiar wavy cleavage of some quartz grains, evidently highly altered orthoclase felspars.	Scaat Craig, U.O.R.
Banded white Felspars.	Eastern pattern [orthoclases]. Probable origin—*paleogranite.*	Auchinroath, L.O.R.
Zoned Felspars.	Western pattern [plagioclases].	Cornstone, in abundance.

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Class of Grains.	Characters of Grains.	Where First Observed in Sandstones.
Hornblende.	With quartz attached, showing radiating needles as in local diorite.	Auchinroath, L.O.R.
Crooked Needles in schist, derived fragments.	Schists along margins of granite veins, Rothes Burn.	Scaat Craig, L.O.R.
Magnetite, zircon, garnet.		All first observed in the very oldest beds of L.O.R. Rothes Burn.
Porphyrite Fragments.	Locality not known. [*In situ* at Gollachy mill; but this is much earlier than the inter-bedded fragment there.]	Auchinroath, L.O.R.
Triclinic Felspar.	With apatite inclusions. Probable origin—*diorite*.	Dipple, L.O.R.
Magnetite.	With weathered felspars and hornblende attached, evidently from western zones of diorite, which are poor in quartz grains.	Scaat Craig, abundant U.O.R.
Balintomb schist, and in schist under Craigellachie Granite Vein.	Tufted sillimanite needles.	Dipple, L.O.R.

Having identified a number of classes of grains at a particular horizon, say, at Auchinroath or Gollachy, it becomes possible to indicate in a general way the course of the rivers that conveyed the detritus to these spots. Thus at Auchinroath we find noted the occurrence—(1) of the Glengrant granite; (2) the intrusive vein in the diorite; (3) the diorite itself; and (4) the intervening schists in abundance. We have simply to join the points indicated to one another and to the nearest point of the margin of the old lake to get, in a general way, the course of one of the rivers of the period. At Gollachy, again, we have, in addition to the groups now given—(1) An assemblage of fragments derived from rocks such as now lie in the lower Fiddich basin [the sand of the present river showing many classes of identical fragments]. We have also (2) quartz grains derived from both the Craigellachie granite veins, and (3) the sillimanite needles from Balintomb or Craigellachie. If we produce the Auchinroath river slightly backwards, we bring in the sillimanite needles; then by adding another river, branching east and west along the margin of the Craigellachie veins, producing its eastern branch backwards on the lower Fiddich area; and finally, making the two rivers meet

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before reaching Gollachy, we bring together the whole assemblage of fragments represented in the Gollachy beds. Again, so many grains, derived from the large granite vein, which crosses both the Rothes and Glengrant burns appear in the Reptiliferous beds that we can hardly resist the conclusion that a river ran for a considerable distance along the outcrop of this vein for the greater part of the period. These and other hints as to the drainage system of the old land surfaces crop up from time to time. But the foregoing examples must needs suffice. They show, at least, that "there is something in it."

But to return to our quantitative results, specimens from all exposed parts of the sandstones of Eastern Moray have been subjected to analysis by the method just described, and the results have been tabulated in series in the chronological order of the beds, so far as that is known. Each entry in these columns is the mean of two, frequently the average of three or four parallel determinations of the same sample. But the tables now exhibited show only the generalised results, and these have been arranged with a view to facilitate the drawing of certain deductions therefrom. First of all we have seven analyses—three of rocks *in situ* and four of fragments of sandstones, found scattered through the conglomerates of L.O.R. age. These latter must perforce represent beds of a very remote antiquity. The beds *in situ* on the Rothes Burn, as far as can be made out from the ground, have been thrown down by trough faults. They stand almost on edge, faced up on both sides by the local quartzites. They have evidently been subjected to intense pressure. The pebbles in them are flattened and ribbed just like figs that have been tightly packed in a box. The included fragments are quartzites showing a much lower grade of metamorphism than the rocks among which they lie, fragments of various mica slates and clay slates, and generally of rocks that now lie wholly to the east of their position. The great age of these beds may, therefore, also be admitted. Now what does the examination of these rocks and fragments go to show? That not a particle of granite, not a particle of true gneiss, is represented in any one of them. Not a grain of them has been found showing typical acicular or typical irregular inclusions such as we find in granite. Ten fragments of clear quartz, such as might be supposed to be derived from granite taken from the Rothes Burn Conglomerate, were broken down and examined. In these not a single needle was found, and irregular inclusions were scarce and ill-formed, and unaccompanied by regular inclusions, such as we find in the local granites. They were referred mostly to vein quartz. The typical inclusions of

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gneiss are absent also. Apart from the schist fragments, of which all these specimens show a very high proportion, the individual quartz grains are uniformly smaller in size than the average of gneiss or granite-derived quartz particles. In confirmation, too, of the conclusion just arrived at, not a particle of felspar is recorded from the whole group. Now it is certainly very remarkable that all these specimens found, or existing under conditions that point to a very remote antiquity, should be quite unanimous in the verdict: "No gneiss, no granite." We cannot but conclude that both of these rocks were absent from the area then undergoing denudation. During the period represented by these rocks and fragments the granite of Benrinnes was not uncovered, for the Rothes beds, which, with the exception of the small outlier at Dufftown, are the nearest of the L.O.R. formation to the present mountain, give no indication of the waste of its granite.

If denudation of this granite had been going on, it would be very odd indeed if some of its waste did not reach the Rothes area, and the view now taken is confirmed by what we find in the ascending series of the L.O.R. beds. In these granite begins very gradually to appear; in fact in the very earliest it is sometimes difficult to be certain that it is represented at all. The next ten determinations show an average of three acicular and six irregular inclusioned grains in 100 grains of quartz. This is higher than the average ratio of the gneiss and schist series alone. We may therefore conclude that granite is present. Indeed, fragments of granite occur in some of the upper beds of the series. But it will be observed that the granitic ratio of this series of beds does not correspond to the typical eastern or Benrinnes ratio. It has the opposite character of the irregular grains, predominating in numbers over the acicular. It was long held as a sort of convenient hypothesis that this might represent the waste of another granite, but this merely as a possible explanation of the peculiarity shown by these beds. But in my last traverse of the area I came across some crumbling fragments of granite in the conglomerate on the Auchinroath Burn. Several of these were easily identified as belonging to the Glengrant granite (which, for more than one reason, I believe to be the very oldest granite to be found *in situ* in the neighbourhood). Its locus is not a mile distant from the spot where these fragments were found. But along with these was a gray variety which puzzled me. It did not correspond in its characters to any of the local granites; and when its quartz particles were evaluated, it gave the formula R_{35}, A_{18}, I_{35}, N_{12}, thus differing very considerably from any of the observed granitic ratios. Was this, then, an actual chip of the palæo-

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granite,[1] whose existence had formerly been believed in simply as a convenient myth? Where did or does the present rock lie, and have we any hope of discovering it? are questions that naturally suggest themselves, but to which we are, at the present moment, without hope of definite answer. The single exception to this ratio, observed in beds believed to belong to this division of L.O.R., is the small outlier at Dufftown, which shows the Benrinnes ratio. Its proximity to the Ben would be sufficient explanation of the earlier appearance of the granitic waste of that mountain here.[2]

When we pass upwards in the series beyond the fish beds of Tynet and Dipple, the suddenness with which the normal Benrinnes ratio manifests itself is indeed phenomenal, and from the horizon indicated to the top of the L.O.R. series, this ratio obtains in every bed that has been examined. It will thus be seen that the L.O.R. beds fall naturally into three divisions.

1. A very early one, represented now by only a few beds *in situ*; but judging from the sandstone fragments scattered through the L.O.R., once much more extensively developed, largely removed by denudation in very early O.R. times, and characterised by the absence of any indication of the presence of granite or gneiss in the area from which its detritus was derived.

2. A period represented by beds, extending upwards, from what has hitherto been considered the base of the L.O.R., to the fish-beds of Tynet and Dipple, and characterised by the waste of a granite or granites, other than those now undergoing denudation in the area, and

3. A period represented by the beds between the fish bed and the top of the series, and which is characterised by the waste of the granites now in evidence.

It is not contended that the Benrinnes type of granite does not appear in the intermediate period, or that the Palæogranite does not extend into the closing period of L.O.R. times. The predominance of the one granite in the one period and of the other in the succeeding is the point insisted on.

[1] Altogether four fragments of this granite have been examined all from Auchinroath. Running through one of them was a band of quartzite, so that like a number of the intrusive rocks of this locality it has probably been intruded along the quartzite-schist boundary line. It contains both muscovite and biotite. I have no hesitation in referring to it the beautifully banded white orthoclase fragments seen in both the L.O.R. and U.O.R. beds of the Elgin area.

[2] As fragments of the local granites are found in the basal conglomerates of the O.R. further west, we must conclude that either (1) these granites (Ardclach and Kinsteary, &c.) are older than the Benrinnes granite, or, alternatively, (2) that the first manifestations of the O.R. in Eastern Moray are of earlier date than the basal beds to the west.

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Coming to the U.O.R. beds, we find again a series of subdivisions; but here, it may be remarked, the microscope only confirms and supports the naked eye examination of these rocks. The differences are evident on inspection, and four divisions are very easily differentiated in the U.O.R. of Elgin. We have—(1) first the Scaat Craig division, with which the *Asterolepis* or King's Steps series of Nairn, may be ranked. Indeed, the latter may be conveniently placed as an independent subdivision. In some of their numbers these two came out very close together and though the difference introduced by the eastern and western granitic ratios raises an element of doubt, this result would tend to support the contention that the *Asterolepis* beds are at the very bottom of the U.O.R. of Nairn. Scaat Craig has frequently been considered a sort of palæontological no man's land between L.O.R. and U.O.R. territory proper. Here the waste of western granites has not made its appearance, at least to any marked extent; but in the insoluble residues of the (2) New Elgin Cornstone, which forms the second subdivision of the series, it appears in abundance. This is the only division in which the irregular inclusions predominate in numbers over the acicular, and this stratum representing, as it does, the period of maximum depression, shows the highest relative proportion of granitic waste, and the highest percentage of felspar. One specimen examined showed as much as 48 per cent. of felspar fragments in its insoluble residue, and these were in large proportion derived from the zoned plagioclases of the western granites. The high proportion of felspar in this division suggests the possibility of impure limestones, being, in some cases at least, largely derived from the disintegration of felspars. The next (3)[1] subdivision, embracing the rough beds of Newton Alves and Cloves, can be seen at a glance to be nothing but transported granitic debris; and at Newton in particular flakes of the large red felspars of the western granites are conspicuous and abundant. The table shows that these beds are evidently a mixture of the waste of both Eastern and Western Granites. The U.O.R. series of Elgin is closed by (4) a group of very fine-grained light-yellow Sandstones, shown in Rosebrae, Oakbrae, Hospital, Laverockloch and Bishopmill Quarries. What strikes us most forcibly regarding these is the all but total coincidence of the numbers representing them in these columns with the numbers representing the Reptiliferous Sandstones which succeed them. This inquiry, therefore, makes for establishing a fourfold division of the U.O.R. series of Elgin. It may also be stated that some such division is suggested by the fact of the

[1] I have since come to the conclusion that the order of (2) and (3) should be transposed.

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existence of essential differences in the fossil fauna of the different beds of the series.

On all sides it would appear the question of the succession of the Elgin Sandstones is beset with the very greatest difficulties. Specimens from the slab of the *Holoptychius* found at Cuttieshillock, and from the slab of the *Gordonia Duffiana* from the same quarry—we could not possibly come nearer the dividing line on either side than that—the one being naturally supposed to lie just below, the other just above the supposed junction, gave:—

Holoptychius Nobilissimus R_{26} A_{12} I_1 N_{61}; size, ·002—·008 inches: very fine grained.
Gordonia Duffiana, R_{31} A_{14} I_4 N_{51}; size, ·003—·05 inches: rough grained sandstone.

Not much comfort from these!

It may be affirmed, however, with some confidence that the various classes of sand grains which had been appearing in straggling parties in the L.O.R. beds below, fall into unbroken lines at Scaat Craig, that new classes appear there or in the beds immediately succeeding, and continue right through the Upper Old Red and Reptiliferous Series, that no new class at least of obtrusive characters appears at Cuttieshillock for the first time, and that none of the old classes disappear at that horizon. Now, taking this and the fact of the all but total coincidence of the numbers in the several columns representing both the closing division of the U.O.R. and the Reptiliferous, we can come to but one conclusion, and that is, that the areas undergoing denudation were practically co-extensive during the two periods. This, though it very strongly suggests, does not absolutely imply continuity of the land surface. A period of elevation or subsidence might be followed by a return of the old land area to practically the same level. But that would be more likely to occur after a short than after an extended interval. I cannot, however, in the face of what I believe to be evidence of discordance between the two series, both at Lossiemouth and Cuttieshillock, continue to advocate continuity of conditions. But all the evidence we have goes to show that the intervening period was probably much shorter than is generally supposed. The fact that the U.O.R. beds of Elgin can be divided into several groups, characterised by essential differences in their fossil contents, would itself mark out a longer interval of time for the U.O.R., and by implication would indicate a corresponding shortening of the interval between U.O.R. and Reptiliferous times. When, however, we look at the particles that make up the latter set of beds a little more

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closely, what strikes us as peculiar is the singular rounding of their individual grains (Fig. 2, plate 19), and this, coupled with the low percentage of felspar they show, lower even than the closing series of the U.O.R., gives reason for strongly suspecting some alteration in the conditions of deposit. I see no way of accounting for this peculiarity of the sand grains of the Elgin Reptiliferous—and it is no new observation on Sandstones of Triassic Age—except on the assumption that these beds were largely—not, however, exclusively accumulated by the agency of wind, just as the Culbin Sands have been and are being accumulated at the present day under the same agency—that the Reptiliferous beds are, in fact, simply the Culbins of an earlier day.

It would be a very nice and very "pat" explanation of the concordance of the results of the two series to suppose that the Reptiliferous beds are simply the disintegrated wind-swept debris of the U.O.R. beds below. If that were so, we should naturally expect the average size[1] of the grains to be smaller than the grains of the U.O.R. beds. Unfortunately for the theory, with the exception of the Findrassie and Spynie beds, they are invariably larger. One way out of the difficulty would be to suppose that the U.O.R. beds yielding the Reptiliferous Sandstones were of larger grain than the beds now remaining, and two observations may be recorded in support of this position. These are—(1) The absence of the Rosebrae division of the U.O.R. to the west of Alves, from which direction the Reptiliferous Sands would naturally be blown; (2) the greater fineness of grain of the Sandstones of the Reptiliferous division at Findrassie, Spynie, and also at the base at Lossiemouth. In this respect of increasing fineness of grain, as the deposits are traced from west to east, it will be found, I believe, that the present Culbins also correspond.[2]

The analyses of the different beds of the Reptiliferous series give no indication of a possible subdivision into groups, as in the

Av.

[1] Size, average of grains of U.O.R., ·003—·015 or ·009,
" " Rep., ·003—·022 or ·013.

[2] The existence of sand dunes similar to the present Culbin Sands along the margin of the U.O.R. basin is suggested by the singular rounding of many of the grains in the sandstones of Scaat Craig; the insoluble particles of the Cornstone residue are more rounded still, and in the upper beds from time to time we come across zones of fairly rounded grains. These we might suppose were either blown directly from the land surface, or were washed down by rivers from sand dunes encircling the U.O.R. lake. There is little or no evidence of rounding of the individual grains in any part of the L.O.R. beds (Fig. 1, plate 19) yet examined; and it is, indeed, certainly highly remarkable that grains from the Netherly diorite are found quite angular at Gollachy, in the L.O.R. fourteen miles as the crow flies from their parent rock, while grains from the same source are found at Scaat Craig U.O.R. beautifully rounded, at a distance of less than five miles from their original home.

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formations below, though, to judge from the peculiar distribution of their fossil contents, we are not without hope that such result may one day be attained.[1]

These are some of the conclusions which a survey of the results hitherto obtained would seem to warrant. There are others no less interesting which might reasonably be drawn from them, but this paper is already too long, and I will now stop to notice only two generalisations derived from the analyses of recent deposits—(1) In virtue of the difference of the eastern and western granitic ratios, this method gives promise of enabling us to trace the movements of the ice sheet over Eastern Moray during the later phases of the glacial period with a precision that was before impossible. The evidence derived from this source in no particular contradicts the evidence derived from the dispersal of erratics or the direction of glacial striæ on the rock surfaces, but has invariably been found to confirm and be confirmed by such observations. If we plot in red dots on a map all the observations in which the eastern granitic ratio has been found to prevail, and in blue dots all the observations in which the western ratio has been found to hold, it will be seen that the red dots centre round and radiate from Benrinnes, and the area in which granite veins of that system prevail. Shorewards we have a broad selvage of blue dots, succeeded again by a red one along the sea margin. The blue dots in this area mark the general march of the ice from the west, while the sea sand, it would appear, takes after the prevailing ratio of the sandstones along the coast. Towards Elgin there is a protrusion of red dots as if due to the advance of a local Benrinnes glacier towards the close of the ice-age. Along Glen Rothes to the Barron's Craig, just west of Rothes, a line of blue dots obtains. This is in harmony with what we know from the erratics which the boulder clay here contains, fragments of Upper Old Red Sandstone and also of the New Elgin Cornstone having been observed in it. Again there is evidence derived from the sand grains alone, that during some phase of the glacial period, the ice moved from a point on Hunt Hill straight up the valley of the Fiddich towards Dufftown,—grains from the (1) Netherly diorite, from the (2) granite vein in the diorite, and (3) the sillimanite zone having all been found in the sands of the Lower Fiddich.

(2) The other generalisation was only observed in drawing up the tables for the present paper. It lies in the apparent diminution in the numbers—I say "*apparent*" because some further confirmation is perhaps desirable—of grains containing irregular

[1] The Cuttieshillock area is quite cut off from the other local rocks of Triassic Age (Findrassie and Spynie) by a rim of U.O.R. rocks all round.

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inclusions under the influence of continued attrition of the sand. Note the large number in the river sands, which average 18 per cent. These go down to 6 per cent. in the sea sand. In the Culbin sand we have 15 per cent., compared with the 23 and 24 of the rivers Findhorn and Nairn, from which we have reason to believe they have in large part been derived. Further east at Burghead the same agency has sent them down to 3 per cent. The Reptiliferous sandstones again where, as we have seen, we have reason to suspect the influence of the same agency, show relatively the smallest number of irregular inclusions in the whole group of sandstones. Now, why should this be? If you call to mind that these inclusions which are often present in immense numbers are full of gas and fluid under high pressure, you will be able to appreciate the effect of sudden changes of temperature on them. These grains will be subjected to rapid changes of internal strain, which is at all times, no doubt, very great, and this we would naturally conclude would have a material bearing on the life period of this particular class of grains. When again we take into account their necessarily slightly lower specific gravity, and the greater hold which their surfaces in virtue of their cellular state would at all stages of their disintegration afford for the levers of disintegrating agencies, it will be obvious that as compared with particles of solid quartz their chances of reaching a ripe old age would be but small. We have therefore good reasons for believing *a priori* that such grains are more liable than grains of other classes to be broken up and so to disappear as tangible entities from our results. A specimen of sand I have from South Africa from the peculiar fissured arrangement seen in many of its grains gives colourable ground for believing that some such process is actually at work. We have some evidence then that even among sand grains the law of "survival of the fittest" prevails.

Such so far is the story of the sand-grains. We have been engaged to-night in making an excursion into a new and comparatively unexplored field. We have in fact been engaged in a search with the microscope for the land surface of an earlier day, and like the old law-giver with the land of promise we may, I think, safely say we have seen it from afar. If there is one impression stronger than another with which one returns from the survey it is a heightened conception of the immensity of geological time. As we trace these ancient sediments back to the crystalline rocks from which they were originally derived, the two grand correlatives of geological change—disintegration and redisintegration—come home to us with a vividness and reality never before attained, and if before we were assured of the truth of the grand principle of the conservation of energy we

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are now no less convinced that there is in nature also a great conservancy of matter.

Far away in early Old Red times we catch a glimpse of an old land surface, overlying what is no doubt a land surface still, but the rocks immediately below it are very different from those that now occupy the same ground. Slowly the denuding agencies remove this primeval crust and reveal another class of rocks. Stretches of granite and gneiss gradually appear, and are carved into mountain and valley; land-surface succeeds land-surface; valley gives place to valley; but the old mountain has a strange persistency, and remains a type of permanency in the midst of change.

Behind all, but ever present to the mind, has been the ceaseless sifting of the sands in river, in lake, in sea. The dust of the old lands has been built into the new. We have taken these tiny fragments—witnesses of a venerable past—and asked them to tell us something of the ancient world which they beheld. Their story you have heard, and wonderful as an old fairy tale it has been.

FOUR PRINCIPAL RIVERS (DETERMINATIONS NEAREST SEA.)

	Quartz.					Other—(Schist and heavy particles).
	R	A	I	N	Fel.	
Spey (Orton) . . .	50	10	15	25	12	10
Lossie (Elgin) . . .	60	6	12	22	14	15
Findhorn (Kincorth) .	48	7	23	22	21	6
Nairn (Nairn) . . .	28	5	24	43	27	8
Average . .	47	7	18	28	18	10

SEA SAND.

	Quartz.					
	R	A	I	N	Fel.	Other.
Covesea	46	6	5	43	7	7
Lossiemouth, W. . .	47	7	4	42	8	4
„ E. . .	52	8	7	33	9	10
Hopeman Bay . . .	56	9	9	26	10	4
Burghead . . .	49	7	7	37	15	3
Average . .	50	8	6	36	10	6

BLOWN SAND.

	R	A	I	N	Fel.	Other.
Culbin	45	11	15	29	18	4
Burghead	46	6	3	45	8	7

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RECENT SAND.

	No.	R	A	I	N	Fel.
Washings of Boulder Clays	27	46	12	13	29	13·5
Post-glacial Sands . .	20	47	11	13	29	16·5
Rivers Spey to Nairn and Tributaries . . .	32	57	10	12	21	13·75
Average . .		50	11	13	26	14

QUARTZ RATIOS FROM ACTUAL ROCKS.

GRANITE.

	R	A	I	N	
Red Benrinnes,	2	61	18	19	Neogranite and Neodiorite Eastern Granitic ratio A > I as 5 : 1.
Grey „	5	64	14	17	
Red, Hunt Hill,	3	70	8	19	
	3	65	13	18	
	A to I as 65 : 13				
	or A to I :: 5 : 1				
	R	A	I	N	
Quartz Diorite, Netherly.	1	96	1	2	

	R	A	I	N	
Palæogranite. Fragment in Conglom. Auchinroath,	35	18	35	12	Palæo-granite and Diorite.
Palæo-Diorite fragment, Same locality,	4	42	50	4	
as	19	30	43	8	

Ancient granitic ratio, I > A as 3 : 2.

	R	A	I	N	
Kinsteary Granite,	4	28	47	21	
Ardclach „	14	33	39	14	
	9	30	43	18	Western granitic ratio, I > A as 3 : 2.

SCHISTS AND GNEISSES OMITTED.

	R	A	I	N
Schist Margin of Granite Vein, Rothes Burn,	33	51	2	14

INTERSTITIAL OR CEMENTING SUBSTANCES IN THE VARIOUS SANDSTONE BEDS.

Q = Quartz. = Siliceous.
F = Hydrated Peroxide of Iron. = Ferruginous.
C = Carbonate of Lime. = Calcareous.
Gypsum = Sulphate of Lime „
Fluorspar = Fluoride of Lime. „
Fel. = Felspathic.

} Cement.

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L.O.R.—	
Rothes Burn.	F. and C.
Greens of Rothes, Red Crags E. of Spey.	Uncemented, but grains coated with F.
Dufftown.	
Buckie Burn.	F. and C.
Auchinroath.	F. and C..
„ Burn.	F., uncemented.
Birchfield.	F. and C.
Birnie Conglom.	F. and C.
Coccosteus Bed, Gollachy.	F. and C. and Fluorspar observed in small amount.
Gollachy Burn Conglom.	F. and C.
„ Sandstone.	F.
Dipple.	F. and C.
U.O.R.—	
Scaat Craig.	F. and C.
Newton.	F. and Gypsum.
Metal Quarry, Alves.	F. and Gypsum and Q. and F. in concentric layers.
Bishopmill.	Q. and F. Gypsum in small amount and Fel.
Rosebrae.	Q. and F. and Fel.
Oakbrae.	Q. and F. and Fel.
Hospital Quarry.	Q. and F.
Laverock Loch.	Q. and F.
Stotfield Red Beds.	Q. and F.
Yellow Sandstone, Eildon Hill.	Q and F.
White „ „	Q. and F.
Slab of *Holoptychius*, Cuttieshillock.	Q. and F. and Fel.
REPTILIFEROUS.	
Cuttieshillock Pebble Band.	F. and Gypsum and Q. in small amount.
Upper Zone.	F. and Q.
Quarry wood.	F.
Spynie	Q. and C.
Findrassie.	F. and C.
Lossiemouth Quarry.	F. Q. and Gypsum.
„ Station Cliff.	F. and Q.
„ Harbour Bottom.	F. and Q. and C.
Covesea.	F. and Q. and Barytes.
Hopeman.	F. and Q.
Cumingstone.	F. and Q. and Fluorspar.
Burghead.	F.

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E. of Burghead. F. and Q.
Slab of *Gordonia*, Cuttieshillock. F. and Q., Gypsum in small amount.
Oolite Sandstone, Lossiemouth. F. and Q. and Glauconite.

Sandstones.

L.O.R.—

	Deter.	R	A	I	N	Fel.	Schist	Other.
3 beds at very base and 4 fragments of Sandstone in L.O.R. Conglomerates,	7	61	$\frac{5}{7}$	$\frac{}{7}$	28	0	53	6
Base to Tynet and Dipple Fish Beds,	10	72	3	6	19	5	17	7
Conglomerates, Dufftown,	1	69	9	6	16	2	20	0
From Fish Beds to top of Series,	5	46	15	11	28	6	9	5
Average of whole L.O.R. Series,	23	65	6	6	23	4	25	4
							29	

U.O.R.—

	Deter.	R	A	I	N	Fel.	Other.
Scaat Craig,	2;	46	14	5	35	13	8
Asterolepis Beds, King's Steps,	2;	49	4	10	37	17	4
Cornstone,	3;	27	14	19	40	27	0
Cloves, Alves, and Newton Series,	8;	39	18	10	33	16	2
Of doubtful Classification,	2;	37	14	6	43	16	0
Rosebrae, Oakbrae, and Laverock Loch Series,	14;	30	14	4	52	12	1
Average of whole U.O.R.	31;	38	13	9	40	17	2

"Reptiliferous."—

Deter.	R	A	I	N	Fel.	Other.
20	30	16	4	50	6	4

Lower Oolite, Lossiemouth.—

Deter.	R	A	I	N	Fel.	Other.
4	43	7	4	46	8	1

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XXIV.—*Note on the Occurrence of Vivianite in an Old Lake Bed at Cauldhame, near Linlithgow.* By HENRY M. CADELL, B.Sc., F.R.S.E., F.G.S., Hon. Sec.

(Read 7th May 1896.)

IN the spring of 1896 some field drains were cut in the flat hollow at the head of the Haugh Burn, between Cauldhame and Parkly Craigs, 1½ miles S.E. of Linlithgow. The excavations were not deeper than 3 or 4 feet, but they showed that this hollow was once occupied by a peat moss, and, no doubt, by a small lake at an earlier date. Numerous bones were dug up, one of which proved to belong to the leg of a red deer, and others to sheep that had been "bogged" in former times, while it was reported that stags' horns had also been got here, showing that deer were once abundant in the district. What was, however, more interesting geologically was the occurrence of a considerable quantity of brilliant light cobalt blue vivianite (phosphate of iron) which was found coating the bones and pieces of stone, as well as mingling with the earth and peat. This mineral is not common hereabouts, so far as I have heard, and is due, no doubt, to the decomposition of the bones and the combination of their phosphorus with the iron in the surrounding peat moss. The vivianite must have been produced so as to thoroughly impregnate the soil, and on breaking open the fragments of rock thrown out of the excavation their joints were seen to be covered with a thin film of the blue mineral, specimens of which have been brought for exhibition to the Society.

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XXV.—*Some Geological Features of the Coast of Western Australia.* By HENRY M. CADELL, B.Sc., F.R.S.E., F.G.S.

(Read 16th April 1896.)

DURING a visit to the Pilbarra gold field of Western Australia, in July and August 1895, I had some opportunity of studying in a very cursory way the geological features of parts of the N.W. coast-line of that little frequented region. The geology of Western Australia is very imperfectly known as yet, the great majority of the visitors being interested only in the search for the precious metal, and caring nothing for the pursuit of science apart from the money value that may attach to it. The vast size of Western Australia, the inaccessibility of the interior, and the want of water will always stand in the way of extensive exploration, and, indeed, so far as my observations go, the greater part of the colony is never likely to repay the trouble of exploration, as most of it is, apart from the gold-bearing reefs, quite unsuited for colonising enterprise of a permanent kind. This conclusion may give offence to many people whose interest it is to belaud the resources of the colony, but anyone who disputes my conclusions has but to turn to the map for a moment and note the physical features of the region, so far as these have been made known to us geographically.

Western Australia has an area of about 976,000 square miles, and is as large as the continent of Europe outside of Italy and Russia, with a coast-line of about 3500 miles, and yet there is not a single river of any size in all this vast area. This proves incontestably that there is in the interior almost no rainfall, and that there can be no high continental ranges covered with perpetual snow, so that without any further exploration it is clear the interior is little better than a vast desert, about as suitable for a permanent population as the great Sahara. So far as is actually known by exploration the interior is a waterless, sandy plateau, with low ridges of sand or rock, and depressions here and there occupied by saline marshes, lakes of brine, or deposits of white salt.

The so-called rivers are mostly insignificant streams, many of which are nearly dry, unless during the rainy season, and the inland lakes shown on the maps are, like all lakes that have no outlet, such as the Dead Sea and the Great Salt Lake of Utah, intensely salt and undrinkable while they contain any water,

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and when, as is often the case, they have not been replenished by recent rains, their beds are covered by a sheet of white salt. I am speaking generally just now, as I do not wish to assert that every part of the colony is equally sterile. Two parts of Western Australia have adequate rainfall for the growth of fairly luxuriant vegetation, namely, the S.W. corner between Geraldton and Albany, ranging, roughly speaking, between 29° and 35° S. lat., where the rainfall is at places about 40 inches; and the Kimberley district, in the extreme northern or tropical part of the colony, between 14° and 17° S. lat. The mountain ranges are, for such a great country, low and insignificant, and none of the summits which are near enough the coast to be accessible reach a height of 3500 feet. Some of the highest ranges are said to be in the northern part of the interior, and are estimated to rise 6000 to 7000 feet above the sea level; but as the country slopes gradually upwards towards their bases, they do not present an imposing appearance. Volcanoes are unknown, and every indication points to a long period of remarkable geological quiescence all over this part of Australia. Mr H. P. Woodward, F.G.S., lately the Government geologist, thinks that this state of matters has lasted from the Carboniferous or, even at some places, from an earlier date, and there is, so far as I have been able to ascertain, no reason to doubt that the interior is a very ancient plateau largely composed of crystalline or palæozoic rocks, which have for ages been subjected to continued sub-aerial denudation.

The effect of prolonged atmospheric erosion is to reduce the surface to a flat or undulating plain, and if the rocks are porous, so that water and air can sink down and decompose them, the upper part of the crust loses its original character and becomes soft and rotten to a considerable depth. This is found to be the case in many of the goldfields, where the original rock is so decomposed at the surface that its true lithological character cannot always be determined. The quartz reefs, being quite indestructible, remain hard and strong, and if large often project above the flat country, and form conspicuous "blows" or land-marks like the outcrop of some of our own basalt dykes. Strange to say, however, although this rotting extends to depths of 100 feet or more at some places, there are to be seen at other places outcrops of rock, apparently of the same kind, which are perfectly fresh, with hardly any weathered skin at all. I had not much opportunity of investigating this interesting subject, but one point has occurred to me as worthy of attention here in connection with the study of glacial erosion.

It has long ago been suggested that the areas of Europe and

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North America, consisting chiefly of crystalline rocks, had become, before the glacial period, decomposed to considerable depths, so that, when subsequently overspread and eroded by continental or valley glaciers, the rotted parts could be easily scooped out into lake basins. Now take the case of Western Australia, which has probably never been glaciated, but whose rocks in many cases are identical in character with those of the Scottish, Canadian, or Scandinavian metamorphic areas. If, let us suppose, the West Australian deserts were to be elevated several thousand feet to near the snow line, so that large glaciers would flow from the snow-covered plateaux of the interior, the pressure and friction of the ice, if it operated on the rocks at all, would produce far quicker results on the soft rotten parts than on the hard knobs and ridges, and the depth of the decomposition would be the prime factor at first in determining the configuration of the solid rock surface under the ice. If the ice-cap were now removed, the whole country would be found to consist no longer of a perfectly flat plain with low hills projecting here and there, but of a hummocky uneven tract of rough country, with here and there a knob higher than the rest, just like the "Ceathramh Gharbh" or Rough Quarter in the gneiss plateaux of the west of Sutherland. The denudation of the gneiss plateau of Sutherland is an interesting problem, and although I do not mean to assert that the whole explanation of the general rough uniformity of the "gneiss billows" is to be found in Western Australia, it seems to me that there may be something worth considering in the suggestion I have thrown out. The recent erosion in Scotland has been greatly modified by glacial action, and it is interesting to try to picture to the mind the probable condition of large parts of what are now drift-covered regions, during Tertiary times after long exposure to the air before glacial conditions set in.

There are, however, many points of difference between our climate and that of Australia, and thus it is not safe to draw too many conclusions from a comparison between these far distant lands. For example, the range of temperature between night and day is very great in the tropical part of West Australia. My visit was in the "cold weather," when the midday temperature was not much over 90 degrees in the shade. We camped out in the open air, sleeping on the bare ground with the Southern Cross sparkling above our heads, and when we lay down at dusk a light enough covering could scarcely be found to throw over us. Before sunrise, however, when the camp fire had gone out, we awoke shivering with cold, and found that the temperature had fallen some 40 or 50 degrees perhaps

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during the hours of darkness. In the hot weather the thermometer in the Pilbarra district (which is within the tropics) often rises to 120 degrees in the shade, and some of the rocks become so hot that they can scarcely be touched with safety, while all the water in the wells is quite tepid.

It is therefore clear that the solvent action of water must in such circumstances be much greater than it is in temperate regions, and the evaporation at the surface in such a dry climate must be also very rapid. In the case of porous, well-bedded or fissured rocks containing much felspathic matter, the decomposition is no doubt greatly accelerated by the circulation of warm water through the mass. There are at places extensive deposits of travertine, a cream-coloured or white magnesian limestone or calcareous rock, called by the miners "opaline," in which gold is frequently to be found. This is no doubt a decomposition product derived from the crystalline rocks below. The upper edges of the schists and slates often become white and broken up a few feet below the surface, and the cracks are partly filled by this "opaline" deposit, which sometimes covers up the outcrops and mingles with the sand and gravel of the soil. The deposit is due no doubt to the leaching out of the lime and magnesia by slow degrees, and to the evaporation of the solution whenever it approaches the surface of the ground and comes within the direct influence of the fierce solar rays.

My observations were confined chiefly to the coast line between Albany and Roebourne, a distance of about 1200 miles. At various places I made excursions a short distance inland, the longest of these being from Cossack to Roebourne, Mallina, and the surrounding district, some thirty miles distant from the nearest part of the coast. The coast line at Albany, on King George's Sound, is of gray granite and gneiss, which rises into low rounded hills on either side of the fine harbour. Albany is a well-sheltered, pretty little place, on the slopes of some rounded granite hills, clad with a beautiful flora of mimosas, cycads or "black boys," brackens, and many other plants, and it may be mentioned that this is the only part of the coast at which an arm of the sea has formed a natural harbour large enough to shelter the great ocean steamers from the gales of the Southern Ocean. The conspicuous absence of natural harbours on its long and exposed coast-line will always detract from the commercial value of Western Australia. This disadvantage, like the drouth in the interior, can never be adequately overcome, and it is an unfortunate circumstance that the original settlers chose Perth, near the mouth of the Swan River, instead of Albany, on King George's Sound, for the capital of the colony.

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The absence of natural harbours or estuaries opens up an interesting subject for geological discussion. In countries such as the British Isles and Scandinavia, where the land has sunk within Tertiary or Recent times so as to partially submerge the ancient river systems, the sea has run up the valleys and produced abundant harbours. The famous harbour of Sydney is due to a local submergence of this kind, and indeed it is, in non-volcanic regions, difficult to imagine any other origin for extensive arms of the sea. Rivers have themselves no power to deepen the sea-level outside, but rather a strong tendency to fill up any hollows that may already exist, by the deposit of alluvium and the formation of deltas at their mouths. There is, in consequence of this, a fringe of littoral deposits being constantly formed round the margin of the land, and if the coast is exposed to the full force of the waves, these deposits are increased by the detritus worn away from the shore by marine erosion. Should a slight and temporary elevation of the land take place, the shelving sea-bed will be lifted up to form a raised beach or bluff facing the ocean, but should the upheaval be continuous and slow the land will simply slope gradually towards the sea without producing any terrace-like features along its margin. It is clear in such circumstances that any estuaries which may have previously existed will gradually become shallower as the sea-bed rises, and will finally disappear, leaving the coast-line free of indentations of any importance.

Now this is what seems to be going on round the greater part of the coast-line of Western Australia. The absence of inlets is only a negative proof of the recent upheaval of the land. The amount of elevation has not been very great altogether, but there is clear enough positive evidence that the colony is really a "rising place" in more respects than one, and that this movement has not been confined to the Recent period. Nearly all round the coast there may be observed a flat fringe of sandstones and limestones containing fossils of Tertiary or Recent age. The town of Perth is built on a series of undulating ridges of stratified sandbeds, which form the sloping banks of the Swan River; and occasionally produce low cliffs along its edges. Between Perth and Albany the country is chiefly made up of granite, gneiss, and other crystalline rocks, against which the recent coastal beds abut directly, but 50 miles to the north of Perth a broad belt of Mesozoic strata begins, trending parallel to the coast for over 600 miles, as far as Onslow, at the mouth of the Ashburton River. At Shark's Bay, the most westerly part of Australia, the recent strata, which here form a plain extending 60 miles inland, have at places been cut into by the waves of the Indian Ocean, and present a line of low cliffs

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rising abruptly from the sea. Seen in section from the deck of the passing ship they seem to rise horizontally or in a slightly undulating position, and to be yellow, tawny, or brilliant red in hue. The red beds seem to be the hardest, and thus form headlands or features along the top of the bluffs, while the lighter-tinted strata below them appear to be softer and more easily disintegrated. Generally there is a long, flat, or shelving beach at the base of the bluffs, which, by the way, are dignified with the name of "ranges" in the absence of any eminences in this part of the colony that are really worthy of the title. The vegetation is thin and scrubby, and there are no trees of any size to be seen. The sea outside, which is inhabited by sharks, is shallow and full of shoals and coral reefs, very dangerous to navigation of vessels of any size, and the general belief among sailors seems to be that it is becoming distinctly shallower all along the western coast. Indeed, there are at Fremantle, the port of Perth, many old colonists who remember when land now quite dry was daily covered by the tide. From the necessarily cursory examination I was able to make, there remained in my mind no doubt about the recent elevation of the coast, and all the evidence went to indicate that a steady upward movement is still in progress. The inner belt of Mesozoic rocks, fringed by strata with fossils of forms similar to those still living outside, shows that the old palæozoic ridge has been slowly rising, at intervals, perhaps, since the beginning of the Tertiary period. At Cossack the old crystalline rocks come down to the sea and form a rough, ragged coast-line and scattered islands without any fringe of later strata. This is, however, only a temporary interruption, as the country to the north again resumes the form of a perfectly flat, low plain, extending away northward for 500 miles to King Sound, with hills of palæozoic or crystalline rock projecting through it, like islands here and there. Raised beaches have been noticed further north at Roebuck Bay, near Broome, on the 18th parallel S. lat. These are from 10 to 15 feet above the present sea level, and one which is from 12 to 18 miles wide extends 25 miles inland. They are covered with salt grass and samphire, and contain recent marine shells. The whole coast-line is, from the scenic point of view, barren and dismal in the extreme, without a single interesting feature to redeem its flat monotony, or remove the impression of sadness and disgust that is left on the mind of the passing traveller. The shores of the Gulf of Suez are also dry and treeless, but the aspect of desolation and scorching heat pervading that ancient wilderness is somewhat relieved by the view of the grand peaks of the Sinai range in the distance. In this part of Western Australia there is the treeless dun-coloured

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sandy wilderness, inhabited by snakes and venomous insects, and the same warm glittering sea dashes on its borders, but not a single hill raises its jagged crest to break the line of the dreary horizon, and the wretched little shanty villages along the shore that pass for towns just add to the general sadness of the whole picture, and make the visitor profoundly thankful that it is not his lot to drag out a dreary existence in such a region.

Dismal as it is, the coast of Western Australia is not wanting in features of geological interest. The theory of the origin of coral reefs and atolls, as originally propounded by Darwin, involves the supposition of the subsidence of great oceanic areas. Now, coral reefs and atolls are abundant in the ocean round the western and north-western coast of Western Australia, and if Darwin's theory is to be accepted, we must suppose that instead of rising, the whole of this area is slowly sinking. From what has been said it is evident that, on the contrary, the long coast-line of Western Australia is steadily rising, and has been on the whole moving slowly upwards for a long geological period. This is, as already stated, proved by (1) the flat fringe of recent fossiliferous rocks round the coast; (2) the raised beaches; (3) the absence of natural harbours; (4) the observations of the older inhabitants as to the alteration of the sea level during the last half century. The movement of upheaval is not confined to the western coast line, as the southern coast line also bears evidence of recent elevation all along the Great Australian Bight. There is, in fact, not a particle of evidence of any movement of depression here within recent geological ages, and it is hardly conceivable that while the land and surrounding coast is steadily rising, the sea bed a short distance further out should be subsiding as steadily. My view is that Darwin's theory, beautiful as it appears on paper, entirely fails to apply here, and that the evidence rather goes to support the theory of Dr John Murray, of the "Challenger" Expedition, who explains the origin of coral reefs in a natural way without demanding great subsidences of the sea bed, of which there is otherwise no clear geological proof.

The palæozoic, eruptive, and crystalline metamorphic rocks in the Roebourne district have been as yet very imperfectly examined, and judging from their great variety and complexity, it would take a long time to investigate them in any detail.

The journey of seventy miles from Roebourne eastwards to Mallina was chiefly over a perfectly flat plain, covered with tufts of coarse grass and prickly spinifex. The ground is brown and sandy, with wind-worn pebbles of amygdaloids, agate and quartz, and here and there knolls of crystalline rock or bare insular-looking brown ridges rising over the prairie-like expanse.

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The oldest rock of the district is apparently the archæan gneiss, which is well seen in the bed of the Big Sherlock River, where the road to Mallina crosses it. The river during dry weather is little better than a row of pools in a shallow channel lined with eucalyptus trees. The gravel beds of the plains have been excavated down to the rock, whose surface is quite hard and fresh. The gneiss is a coarse gray granitic rock, similar in character to much of the archæan platform of Sutherland, but so far as I noticed it has none of the pegmatite veins so common in the north-west Highlands. In this gneiss there are distinct traces of a double foliation. The older and coarser banding has a north and south strike at the Big Sherlock section, and at right angles to this there are zones of secondary and much finer foliation, within which it has the character of a mylonite or a fine quartz schist, perfectly distinct from the original rock, and identical in appearance to the sheared gneiss along the belts of thrusting that traverse the Sutherland archæan area.

Many knobs of other varieties of gneiss, sometimes beautifully banded, project through the plain, as well as bosses, dykes, and ridges of granite, diorite, gabbro, diabase, and basalt, felsite, porphyrite with finely striated plagioclase crystals, and other massive rocks. The diorite is sometimes perfectly fresh, with only a thin brown weathered skin. At other places it breaks up and weathers in huge heaps of a rich deep brown umber hue, that look more like enormous peat stacks than anything else. I obtained specimens of these rocks, but have not yet had time to investigate carefully their petrographical character.

The rainfall of the region is very small, and sometimes does not exceed 6 inches in a year, but occasionally there are torrential storms, when the rivers rise 20 or 30 feet in a few hours and sweep along enormous quantities of dust and sand.

Where the rock is rotten and soft a large quantity of the rain sinks down to "water level," which, in the Mallina district, is about 45 feet to 50 feet below the surface. By sinking wells a fair supply of fresh water can generally be obtained at this depth all over the district, but for which it would be almost uninhabitable.

The plains are at places very thinly covered with surface deposits, and for distances of several miles I noticed that we were crossing a platform of granite, clay-slate and other rocks, whose surface had been planed down quite flat by denudation. This looked to me like a plain of marine denudation of a very perfect kind. It has often been remarked in the North-West Highlands that the Cambrian Quartzite rests on a perfectly flat pavement of more ancient rocks, that have by some process been planed down in a remarkably uniform manner. This part

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of Western Australia looks at places very like the ancient Cambrian sea-bed were the quartzite stripped off it. Whether the Westralian plain has been smoothed flat by marine or subaerial erosion, I had not an opportunity to investigate. It appeared more like an ancient sea-bed than anything else, across which the waves could sweep uninterruptedly for many miles, towards the bases of the high knolls and ridges that may have been bare islands like those around the present coast. Many of these eminences were no doubt completely worn away, but the process of marine erosion was brought to an end by the rise of the sea-bed and the consequent gradual retreat of the ocean to its present position. It left behind it a long smooth plain, sloping downwards by imperceptible degrees to the coast, fringed at the edges with mangrove swamps, and salt marshes covered only at spring tides.

In course of time the plains became covered with tufts of prickly spinifex, sparse grass, a great variety of rare and beautiful flowers, and patches of bush of scrubby gum-trees, inhabited by kangaroos, wild turkeys, snakes and centipedes, and vast colonies of ants, whose brown hills, 10 to 14 feet high, are studded over parts of the plain at regular intervals like hayricks, and form quite a feature in the otherwise most uninteresting landscape. Last of all must be mentioned the native human inhabitants, who are as black as coal, very low in the scale of intelligence, and as forbidding and hopeless in aspect and character as the dismal country in which it is their unhappy lot to dwell.

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ONE OF NORTH ISLAND, N.Z.

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MAP SHOWING THE VOLCANIC Z

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XXVI.—*A Visit to the New Zealand Volcanic Zone.* By HENRY M. CADELL, of Grange, B.Sc., F.R.S.E., F.G.S. (Plates V.-X.)

(Read 16th April 1896.)

To the Scottish geologist, whose acquaintance with volcanic phenomena in the field is confined to eruptive rocks old and cold, deeply buried, perhaps, beneath Palæozoic strata, or associated with fossils of the far-off Miocene age, and everywhere greatly denuded and covered with marks of hoar antiquity, a visit to a region where volcanic action is still rife is a profoundly interesting and instructive experience. To see the ground rent by eruptions and split open by recent earthquakes, and to follow the outcrop of a fault perhaps only ten years old, and trace it across a valley and up a hillside, as one might trace a furrow or the track of a cart across a field, is a geological luxury that cannot be enjoyed in our solid old country. In text-books we read of the effect of a fault crossing a valley and throwing a wide part down against a narrow part higher up stream, producing a waterfall at the crossing, and a sudden widening of the glen immediately below it. Such a thing is unknown with us, where the inequalities of the surface due to large displacements have long ago been smoothed away by denudation. In the Thames Valley this very phenomenon, which will again be referred to, is distinctly visible, and many others of an equally interesting character can be studied all along the volcanic zone of the North Island. The limits of the volcanic area and the principal hot-springs, geysers and active or dormant volcanoes are indicated in red on the accompanying general map of the North Island (Plate IX.).

The North Island, which I visited in September 1895, is almost entirely volcanic in character, and the eruptive rocks are all of Tertiary or Recent age. The beautifully-situated town of Auckland is surrounded on all sides by evidences of recent volcanic activity. Happily its volcanoes are all extinct now, but during the later Tertiary or the Pliocene period the whole district was a seat of intense eruptive energy. From the top of Mount Eden, an old crater behind the town, a multitude of small cones and craters can be descried, some of them scattered like large molehills over the mainland, and others on islands or headlands surrounding the magnificent harbour.

In the Hauraki Peninsula, which is separated from the Auck-

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land district by the Firth of Thames and the Hauraki Gulf (see Map, Plate IX.), volcanic energy appears to have first manifested itself in the Upper Eocene period. A great series of submarine eruptions took place, by means of which a bank of volcanic materials was built up on the ocean floor. Associated with these lava beds is a band of ash known as the "Parnell Grit," containing fossils which indicate the period of the first volcanic outbursts. In course of time many of the volcanoes rose above sea level, and the land surface, during a temporary cessation of volcanic activity, became covered with a luxuriant growth of vegetation. When the subterranean fires again burst forth with renewed energy, the forests were overwhelmed and covered by hundreds of feet of ashes and lavas, first of a semi-basic and then of a trachytic character. During the subsequent time of diminished volcanic activity the embedded trees were in many cases converted into wood-opal by the petrifying action of thermal springs. Great earthquakes were no doubt prevalent in the district, while the cracking of the rocks as they cooled and contracted gave rise to numerous deep-seated parallel fissures running in a general north-and-south direction. Heated vapours, sulphuretted hydrogen, steam and acid gases rose through these channels, and appeared as solfataras and fumaroles, such as are still abundant in the Rotorua and Tarawera districts. These chemical reagents permeated the rock and gradually decomposed it more or less completely, until its original character was quite altered. Mr James Park, F.G.S., lately director of the Thames School of Mines, believes that the metallic constituents and silica were carried in solution along the fissures, and that these seem to have acted like voltaic cells in which a strong electro-chemical action was set up. The basic solutions were thus apparently decomposed and their metallic constituents deposited, the base materials and part of the silver as sulphides, and the gold, together with most of the silver, as metallic alloy.

Since the last of these eruptions ceased, the greater part of the Hauraki district has remained undisturbed by volcanic action, and the agencies of denudation have during the remainder of the Tertiary epoch been busy wearing down its surface and eroding its stream-channels. The decomposition of the volcanic rocks has made them very soft and friable, so that they offer comparatively little resistance to the action of the rain and running waters. When visiting the Yellowstone National Park in America, which in many ways resembles this part of New Zealand, I was much struck with this softening action of heated springs and fumaroles on hard volcanic rocks. The magnificent cañon of the Yellowstone river has been eroded out of hard

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WAIROA TOWNSHIP BEFORE THE ERUPTION.

Lake Tarawera in distance.

SITE OF WAIROA AFTER THE ERUPTION.

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rhyolite at a comparatively rapid rate, the rock having become completely rotted away by heated waters and vapours percolating through it from below. Little puffs of steam were visible issuing from cracks in the cañon walls, and the hard rhyolite within their vicinity was so soft that it could at places be crumbled away by the fingers, so that the river had little difficulty in scooping out its channel.

Volcanic activity, although apparently extinct in the Hauraki district proper, was only dormant for a time in the central parts of the island. In newer Pliocene times it burst forth with prodigious energy, and huge floods of acid lavas were vomited forth over hundreds of square miles of country, while dense clouds of light pumice, ashes, and dust were belched into the air to fall in thick beds over half the island. Excellent examples of the younger volcanic cones are, as already mentioned, conspicuous all over the Auckland district, and further south the great volcanoes of Ruapehu, Tongariro, and others are still in a state of modified activity. The solid products of these eruptions reached as far north as Paeroa and Waihi, while the ash-beds are found hundreds of feet thick in the Upper Thames valley and the Upper Waikato. The old valleys were filled up in many cases, a circumstance of importance from a mining point of view, as the outcrops of the reefs were also covered, and a correct knowledge of this fact is essential to successful prospecting wherever the newer rhyolites occur. The well-known Martha Hill at Waihi, through which the celebrated lode of the Waihi Company runs, was surrounded but not quite covered by thick masses of rhyolitic breccias and lavas. The outcrop of the lode outside the company's property cannot, therefore, be traced on the surface of the ground, and must be sought for by mining operations underneath the latest rhyolitic lavas.

The auriferous reefs are found in bands or belts of "propylite" or decomposed andesite, separated from each other by hard bands of solid andesite-lava, or indurated tuffs passing into coarse breccias. This propylite is locally known as "sandstone," and is spoken of by the miners as the "kindly rock" of the country, in which reefs may be most confidently expected to occur. The reefs are of the segregated class, having derived their metallic ingredients from the solution of the rock in their immediate vicinity.

Gold is a very widely disseminated metal, and occurs in minute quantities in sea-water as well as in various minerals. In many goldfields, such as those of Victoria and Western Australia, the best gold reefs are found in a clay-slate "country," and this has been explained by supposing that the slate was originally a marine deposit which enveloped small quantities of

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gold at the time of its deposition during the Palæozoic epoch. The action of aqueous solution has subsequently resulted in the leaching out of the gold with other minerals and the re-deposition of them along fissures in the rock.

In the case of the Hauraki district, the gold occurs under peculiar conditions and in reefs of Tertiary age, so that here the marine theory is quite inapplicable. The propylites are the gold-bearing rocks, and wherever the reefs pass from this decomposed rock into the fresh rock (or andesite) or into the tuffs and breccias associated with them, they become poor or sterile in character. The inference seems sound that the source of the gold and silver is to be sought in the pyroxenes of the original andesite, which have elsewhere been found to contain small quantities of the precious metals. It may be mentioned that when visiting the geyser and hot spring district of Rotorua, I was told that small quantities of gold were known to occur in the sinter-deposits produced by the geysers, which helps to substantiate the theory that the reefs were originally due to hydrothermal action.

The minerals associated with the gold are principally iron pyrites, after which come copper pyrites, zinc-blende, stibnite, and ruby silver, as well as galena, manganese oxides, calcite, pearl-spar, and occasionally metallic arsenic, specimens of the last-named metal are often found in the Kapanga mine at Coromandel. Before turning from the gold-bearing rocks, it is of importance to note that after much scientific investigation it has been clearly ascertained that the auriferous propylites of the Hauraki district are the same as the volcanic rocks of the famous Comstock lode and Washoe districts of North America, and are also similar to the "country rocks" of the ancient mines of Hungary and Transylvania.

After the district had passed through the changes described, and most of the fissures had become completely mineralised and filled up by quartz-reefs, a new set of geological phenomena arose. The infilling of the fissures was not quite complete, it may be mentioned, as it is common in the mines of the Thames district to find extensive empty cavities, where the fissures are still open and gaping for hundreds of feet at a time perhaps, or again to strike water-channels or acidulated springs following the course of the rents. Most of the reefs, however, were completely mineralized when the district was again dislocated by earthquake-cracks, such as are still produced during the earth-tremors at other parts of the island.

Two large faults were originated in the Thames gold-field, and their courses are very clearly marked by the alteration they have made on the surface of the country, as well as by

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From Photo. by Mr J. Martin, F.G.S. Auckland.

ERUPTION OF THE WHITE TERRACE GEYSER,

22ND NOVEMBER 1885.

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their important influence on the distribution of the reefs in that district.

The best known of these is the Moanataiari fault, which crosses the trend of the reefs at right angles, and runs along the face of the mountains from Hape Creek to the shore, a short distance west of Grahamstown or Thames. The effect of this displacement is to produce a distinct terrace or step on the mountain-slope, as its downthrow side is towards the sea. It hades to the south-west at a uniform angle of 45 degrees, and it has been calculated that it must have a vertical downthrow of about 400 feet. The fault forms an abrupt barrier to the mining operations on its seaward side, and to regain the truncated reefs on the upthrow side extensive cross-cutting is necessary. When it was first crossed it shed so much water that operations had to be abandoned for a time, and when again the north-eastern cross-cut from the 640-feet level of the Big Pump shaft at Thames reached its face, a huge mass of soft plastic clay rolled down the drift with great velocity, causing the workmen to flee for safety. The lateral displacement is so great that reefs which have been followed from the seaward side have never as yet been recovered on the footwall or landward side. The recent age of the fault is shown by its effect on the surface of the ground, where its course can be distinctly traced. Where it crosses one of the mountain-gulleys it has the effect of suddenly contracting the glen above and lifting the former bed of the stream up opposite the wider mouth of the part below. A broad part is thus thrown against a narrow portion, and a marked and sudden contraction on the upthrow side is clearly visible. Where the fault has been cut in the mines it has, moreover, been found to contain masses of rotten wood, fern-roots, and decayed vegetable matter in the soft "pug" and clays lying under its hanging wall. These circumstances point to the newer Pliocene, or even later age, of this important displacement.

The Hauraki Peninsula, as shown on the map (Plate IX.), is outside the zone of recent vulcanicity, but the Coromandel mountain range, which forms the backbone of the peninsula, extends southwards along the eastern side of the Thames valley to Te Aroha, where the first of the hot springs are to be found. Te Aroha, a pleasant sanatorium, nestles snugly at the foot of the forest-clad mountain of the same name, and its warm sulphur baths are much sought after for their medicinal virtues. To reach the heated region we must continue our journey southwards to Rotorua, the centre of the geyser district.

Rotorua, a township on the flat shore of Lake Rotorua, forms the railway terminus, and as we approach it the smell of

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sulphur in the air, and the clouds of steam circling lazily upwards through the ti-tree bush, show that we have reached a place where the crust is dangerously thin, so that we can hardly consider ourselves standing on *terra firma* proper any longer. Lake Rotorua, a sheet of water about 20 miles in circumference and 1000 feet above sea-level, is, next to Taupo, the largest lake in the North Island. It lies in a roundish depression, not more than about 30 feet deep, which may have been produced by a volcanic subsidence. Abundant signs of thermal activity appear along its shores in the shape of hot springs, boiling mudholes, fumaroles, and sulphur baths, greatly valued by invalids. The surrounding country is uneven and hilly, and is covered by a dense growth of the ti-tree or manuka bush, which in winter has a warm russet brown hue like heather, but is spangled with white blossoms when the bloom is on.

The principal geysers are grouped together at the native village of Whakarewerewa, two miles south of the township of Rotorua. These are exceedingly interesting, but are not nearly so fine or so imposing in their performances as the splendid geysers of the Yellowstone. The art of soaping the geysers, which was accidentally discovered in the Yellowstone Park, is practised here when an eruption is wanted to order; and after trying the experiment, by means of a bar of soap cut up into small pieces and thrown into the funnel, we were successful in inducing Pohuto, one of the principal spouters, to favour us with a very creditable performance. At the sanatorium of Rotorua, on the shore of the lake, some interesting experiments were made a few years ago by Mr Camille Malfroy, C.E., the engineer in charge of the Government works there, after the eruption of Mount Tarawera.[1] These experiments were designed to illustrate Mr Malfroy's theory of geyser action, and went to show that the difference between a fumarole, hot spring, mud volcano, and a true geyser is very small, and depends on the shape of the funnel and the facilities for the descent of water to the heated cavities below. The practical result led the author to conclude that geysers can be regulated and controlled to some extent, and hot springs can be converted into geysers by certain mechanical arrangements, and made to play at will. In proof of this, the hot springs supplying the baths at Rotorua were converted into small geysers at Mr Malfroy's suggestion, and have continued to play regularly for the entertainment of visitors. It may appear sacrilegeous thus to interfere with curious natural phenomena, and thrust iron pipes and concrete into the throats of beautiful boiling springs. To my mind,

[1] For an account of these experiments see Mr C. Malfroy's paper, "On Geyser Action at Rotorua."—*Transactions* of the N.Z. Institute, 1891.

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however, the charms of nature can in this way be greatly enhanced, and one can only regret that the geysers of Whakarewerewa have not been improved a little in their working. There is ample room for scientifically embellishing both their sinter deposits and their surroundings; but the Maoris, to whom they belong, do very little beyond drawing toll from visitors (which is done on correct and most scientific lines), and squatting in the warm pools with their wives and families. A feeble attempt has, it is true, been made to build up the sinter, so as to produce in time a far-off imitation of the lost Terraces, but much more might be effected in this direction, both at Whakarewerewa, Wairaki, and at other places, were the custody of the geyser basins in more intelligent hands. Soaping the geysers has been prohibited in the Yellowstone Park, and other regulations have very properly been strictly enforced for the preservation of their amenity; and perhaps at some future time the Government may see fit to acquire the New Zealand Wonderland in the same way, and improve it for the benefit of the public in all time to come.

Mount Tarawera is about twenty miles by road from Whakarewerewa. The first ten miles are covered on horseback *vid* the old road through the Tikitapu bush to the ruined village of Wairoa. Before the eruption, when the shores of Lake Tarawera were inhabited, and there was a well-populated township at Wairoa, the road was used for vehicles, but it is now merely a bridle track, the greater part of it having been destroyed by the eruption, washed away, or allowed to go to decay for want of use. For the first few miles the road runs along a flattish plain that slopes gently from the high ground towards the shore of Lake Rotorua, and is clad with a bosky mantle of ti-tree bushes. The ground is all made up of volcanic ash of various ages, most of it being light yellow or grey pumice, the product of old eruptions. The ash of Mount Tarawera is dark gray or nearly black, and it is thus an easy matter to tell when we are within the area affected by the eruption. At first the traces of the eruption are only apparent to the trained eye of the native of the district, but soon the layer of dark material becomes evident to the most careless observer. The limits of the ash have been carefully mapped out by Professor Thomas, of Auckland University College, who investigated the district immediately after the eruption, and published a valuable report on it in 1888. As the wind was from the south-west when the outburst took place, most of the ash was blown in a north-easterly direction towards the sea, and scarcely any fell so far west as Whakarewerewa and Rotorua. After leaving the plain the path turns southward through the once luxuriant Tikitapu

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Bush, and follows for part of the way a small valley, on either side of which the hills rise to a considerable height. Moerangi, the highest summit, has an altitude of 2240 feet, and rises steeply from the shores of the Tikitapu and Rotokakahi lakes, whose waters once sparkled like sapphires in the sunlight, but are now as dull as milk, or at least as white as opals without the "fire." The fine bush along their margin is blasted and blackened, and although the luxuriance of the vegetable growth is, after ten years of repose, beginning to reassert itself, and clothe the landscape with some of its former verdure, many years must elapse before the first rude traces of the catastrophe become hidden from view.

One effect of the shower of ash on the physical geography of the district interested me exceedingly, and brought into prominence a phenomenon that can seldom be observed, from its rare occurrence. Where the fall of ash exceeded 6 inches, the whole ground was covered with a dense black skin, which, when saturated with rain, turned into an impervious bed of clay, that overspread hill and dale like a waterproof sheet. Before the eruption the rain fell upon ground thickly overgrown with vegetation, and a great part of the rainfall was thus retained for a time, absorbed, or allowed to trickle into the lakes or percolate slowly and quietly into the porous soil. After the coat of volcanic mud was put on all was changed. The heavy rains no longer fell on a bosky, absorbent surface, but were precipitated on a smooth, watertight cover which, like the slated roof of a house, shed the drops as fast as they fell. The water ran in streams down the slopes, and these united to form fierce torrents in the flat bottoms of the valleys between the hills. These hollows had, in former days, been occupied by small rills that warbled quietly down to the lakes without scooping out deep channels or notably wearing away their mossy sides. When these brooks gave place to roaring torrents that rushed along with wild fury whenever a heavy shower fell, and dried up as soon as the clouds rolled away, quite a new effect was produced on their beds. The waters quickly dug out deep channels, and in a short time their courses were marked by gorges or small cañons with perpendicular sides, which were undermined and further excavated by each fresh spate. The ground rock being of soft, light pumice fragments, with little coherence, excavation was not a difficult matter.

As we approached Lake Tikitapu the road followed one of these stream courses, and we gradually ascended the valley for a few miles riding close to the edge of the cañon cut out during recent floods. Our Maori guide, A. Warbrick, said that the gorge in the middle of the valley had been almost entirely

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formed within the last five or six years, and had no existence before the eruption. It was at places more than 60 feet deep, and the sides were perpendicular or even dangerously overhanging. At one place where the hillside above sloped rather steeply down to the chasm, the path, only about 2 feet wide, ran along the very brink. This was at a bend in the stream where its eroding power was greatest and the depth was 50 or 60 feet. I dismounted and led my horse past it, not relishing the idea of a possible fall over the edge on horseback. If the path were to give way under us it would probably be more comfortable to fall separately. After passing the critical place I looked round and found that the cañon wall was really overhanging, and I made up my mind that when we came back

another way past must be found out. When we did return in the evening there was no need of impressing this caution on our guide, as the path had disappeared during our absence into the chasm! The above sketch, which was taken a short distance further up the stream, illustrates roughly the appearance of this last product of the eruption. The walls of the gorge reveal an excellent section of the stratified pumice beds with which the old valley was filled, and at the time of our visit the weather was fortunately dry, so that the bottom of the stream channel was quite bare.

The steepness of the walls shows that the process of excavation is rapid, and that the natural disintegration by the atmosphere

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and rain is quite insignificant compared to the erosion by the stream, just as it is on an infinitely greater scale in the celebrated Grand Cañon of the Colorado. The old valley, on the other hand, is shaped like a roofing tile, showing that the tendency to crumble away at the sides was formerly greater than the tendency to undergo deepening through the stream's action. An excavation of this sort starts at first by the stream eating down its bed near the lower end, where it debouches on flat ground and has a "free toom," as we say in Scotland, or available space to deposit its burden of detritus in the shape of a fan or delta. The gorge begins at the apex of the cone, and when once started eats its way steadily backwards up the valley, deepening and widening its section as it grows in length; and so long as the fall is great enough to let the stream carry away all the detritus, the process will go on. As we proceeded on our way this was made quite clear, for the chasm grew smaller and narrower, so that at last we could step across it, and it finally dwindled down to a mere fissure a yard or two deep, with vertical walls entirely bridged over at places by the vegetation. In this case there is evidence that the original fissure was partly produced by an earthquake crack, but the quantity of material washed out of it by water showed clearly that it is to the action of the stream that its present size is due.

This is only one, and perhaps not the best, example of a process that is going on all over the ash-covered district. Professor Thomas told me of other and much deeper gorges produced in the same way. Now it is interesting to note that this is only a temporary phase of the physical evolution of the region. Provided no fresh eruptions occur, the ashy covering will be gradually washed off the hills, or at least the deposit will disappear under the growing vegetation, so that the sudden torrents will diminish in force and erosive power. The sides of the gorges will fall in, as it is not natural for soft strata to stand long in the form of vertical cliffs where the climate is moist and the rainfall abundant. Small but regularly flowing streams will again occupy the channel, and these will not be able to transport all the stuff that falls into them, so that in time a smaller tile-shaped valley will be formed inside the greater, and a step-like feature along the hillsides will be all that remains of the original perpendicular cañon walls shown on the sketch.

In the Taupo volcanic district the tributaries on the right bank of the Waikato river, which is far beyond the area of the Tarawera ash, have cut cañons with vertical sides 200 feet or more in height. Professor Thomas points out that the preservation of the walls is largely due to the porous nature of the pumice strata, which allows the rain to sink into the ground

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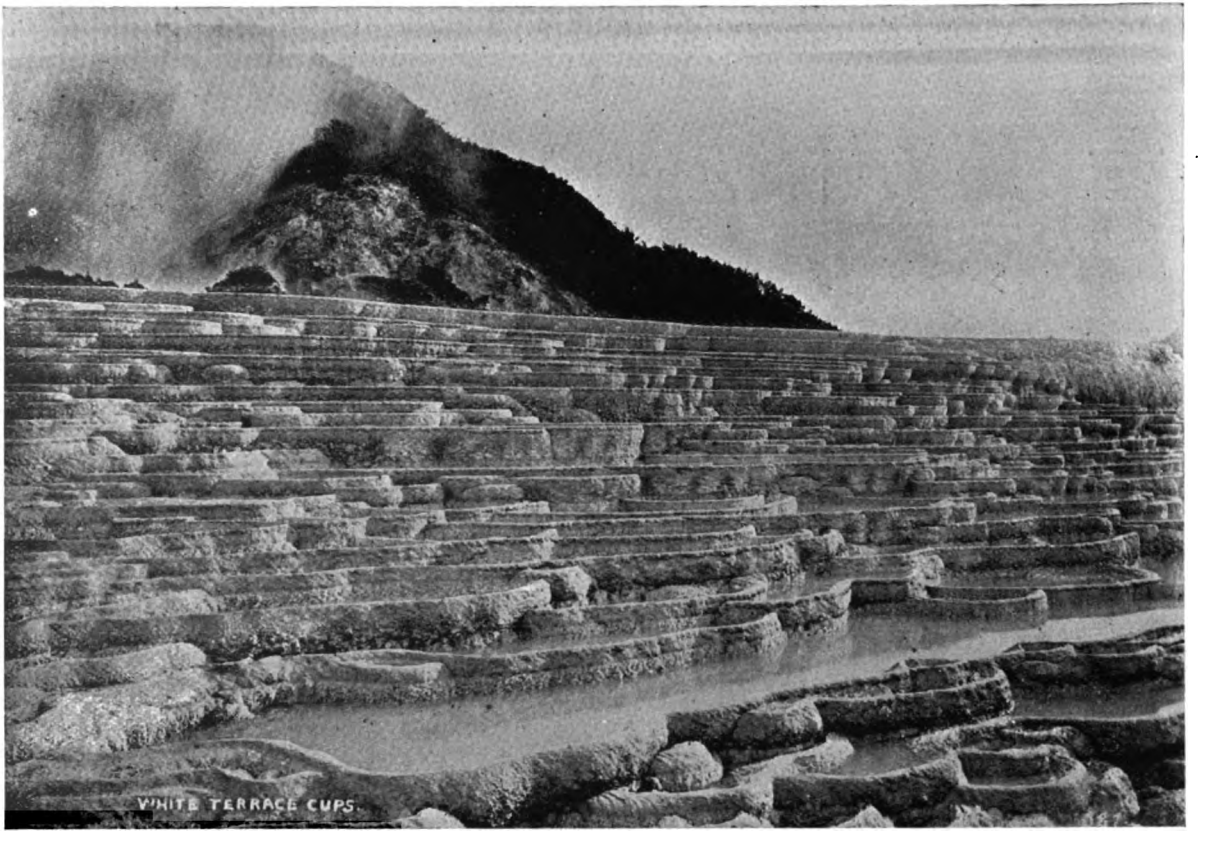

From Photo. by Mr J. Martin, F.G.S., Auckland.

THE WHITE TERRACE CUPS, LAKE ROTOMAHANA.

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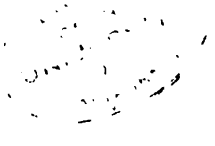

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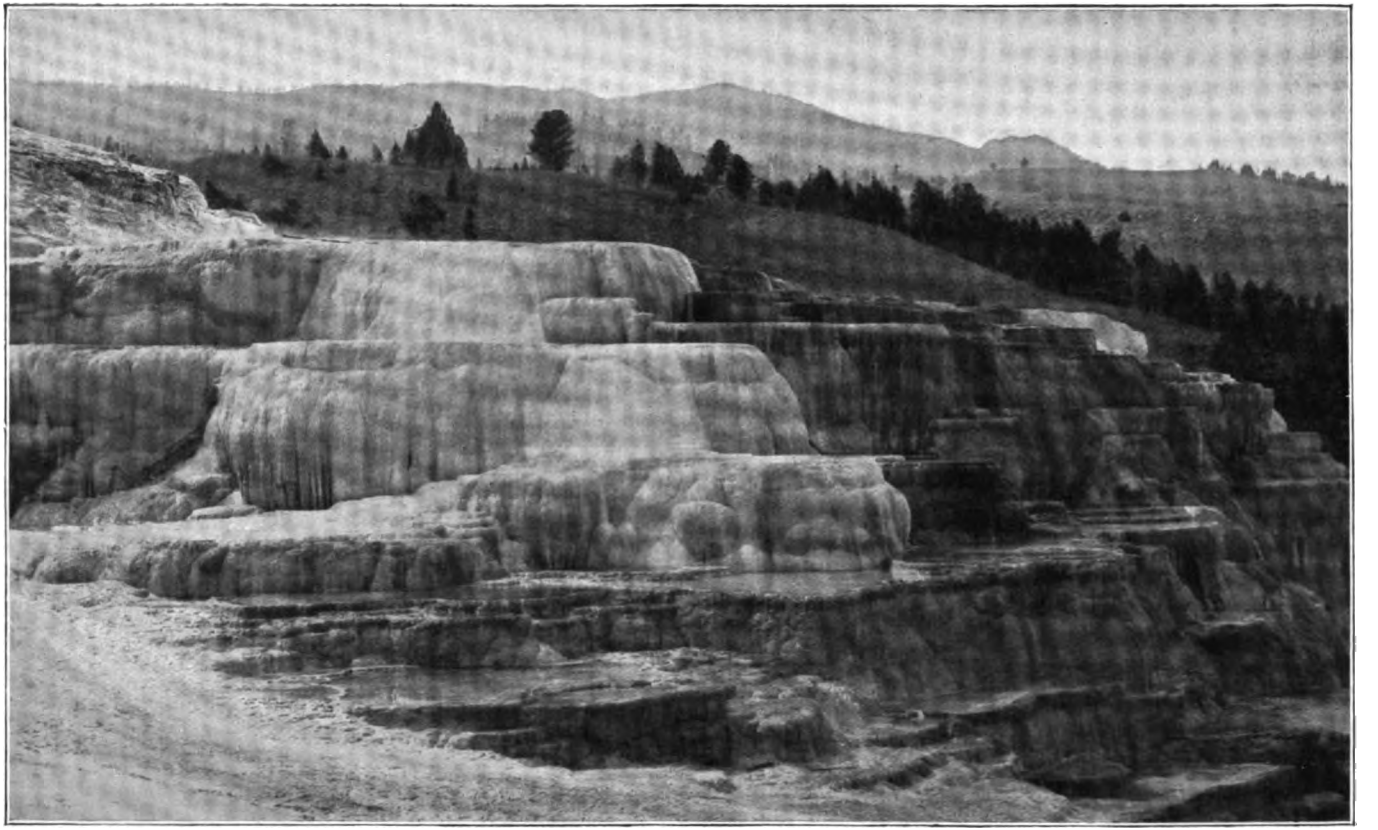

MINERVA TERRACE, MAMMOTH HOT SPRINGS, YELLOWSTONE PARK.

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instead of streaming over the surface and wearing away the margin of the cañon. The preservation of the walls of the Grand Cañon of the Colorado is due, on the other hand, to the very small rainfall of the part of America across which the greater part of the river has formed its bed. The absence of frost is also conducive to the preservation of sharp natural features of this sort, since soft, porous cliffs would, in a wet region nearer the Poles, be particularly liable to disintegration by the winter's frosts.

The native township of Wairoa was, up till June 1886, a smiling village, beautifully situated in a valley, amid luxuriant forests and well-tilled land, on the banks of the stream that falls from Lake Rotokakahi into Lake Tarawera. It is now a blasted and blackened waste, with ruined houses half buried under ashes (Plate V.); and the solitary inhabitant that met us was a brown cat, the only resident that had, after escaping with a whole skin, apparently thought the place still attractive enough for a permanent residence. The trees were partly burnt and partly overthrown by the fury of the indraught of wind caused by the eruption; but these are now sprouting again, and the dull, leaden grey of the landscape is becoming enlivened with spots and patches of warm russet brown or green. Professor Thomas has calculated that Wairoa is situated at the outer edge of the area over which the ash fell on the average 3 feet deep, and as we approach the volcano the depth of course continually increases. A fall of from 2 to 3 feet of ashes and mud may not seem a very serious matter, but it was quite enough to crush in the frail roofs of the houses and cause the death of over a dozen persons. The eruption took place suddenly in the small hours of the morning, and in the pitchy darkness it was impossible to escape. The two native villages of Te Ariki and Moura, on the shores of Lake Tarawera, near the volcano, whose sites are indicated on the accompanying map of the district, were entirely overwhelmed, and not a soul was left to tell the terrible tale of their destruction. Altogether 111 natives and Europeans were killed, the majority of the inhabitants of Wairoa having survived the eruption, which, though terrific while it lasted, happily did not last long, as it was all over, so far at least as the ash shower was concerned, in about five hours. Although large volumes of steam continued to rise from the newly-formed vents for months afterwards, no fresh explosion has since taken place, and the mountain has been steadily cooling down for the last ten years, almost no steam being now emitted from the craters.

We left our horses at Wairoa, and clambered down the steep path past the charming waterfall at the head of an arm of Lake Tarawera, to the white beach of pumice and obsidian sand, where our Maori guides had a boat ready to take us to the volcano on

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the opposite shore. As we rowed across the milky waters our boatmen related how, eleven days before the eruption, the inhabitants of the native settlements on the shores had been startled by the form of a huge phantom war-canoe moving stealthily over the lake, coming from an unknown port, and going no one knew whither. The meaning of this apparition was not understood at the time; but after the catastrophe was past, the few survivors were convinced that this had been an omen from the world of spirits to warn them of the approach of the destroying angel.

The length of our little voyage was about eight miles, and we landed in a bay where a torrent had cut out a gorge in the black scoriæ and spread out the detritus in the form of a broad fan sloping gently downwards to the beach. The configuration of the ground has here been entirely changed by the eruption. For miles around, the shores of the lake, once decked with luxuriant vegetation, are now deeply buried under a leaden-grey coating of volcanic mud and scoriæ. The surface of the ground is cut up with multitudes of deep, wavy furrows, as if it had been raked all over with gigantic combs. At places these furrows are so deep and numerous that they resemble glacier crevasses, and make the country quite unpassable for man or beast. They can be seen miles away from the neighbouring hills radiating outwards and sweeping in regular curves corresponding with the changes in the slope of the ground. A good impression of the remarkable appearance of the district may be gained by looking at the hill shading on some of our ordnance maps, whose black radial hatchings bring to mind the black, sharp groovings in the scoriæ hills round Mount Tarawera.

Mount Tarawera is an ugly, flat-topped mass that rises steeply from the lake, and at the water's edge terminates in abrupt cliffs. The lake is about 1000 feet above sea level, and the mountain rises over 2700 feet higher, so that the climb is not a matter involving much expenditure either of time or muscle. The upper part of the mountain is entirely made up of black or reddish scoriæ, lapilli, and dark rounded bombs or "fireballs" of augite andesite lava, with a vesicular spongy core and a hard shell rather smooth at times on the surface. In many cases, however, the core is seen to be a lump of white, hard rhyolite, the rock of the original Mount Tarawera. This has been blown into fragments, many of which were wrapped round with a skin of the black andesite lava during the progress of the late eruption.

On reaching the crest of the ridge a strange scene presented itself. After climbing the steep, ashy slope, we came suddenly to the brink of the great chasm that has cleft the mountain into two parts. This huge fissure extends for a distance of over nine miles through the top of Tarawera and the site of Lake Rotoma-

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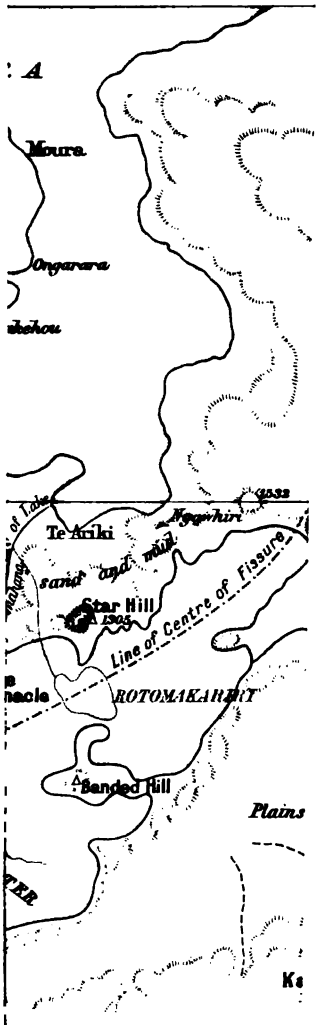
AWERA DISTRICT
LAKE ROTOMAHANA AND



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hana at its base, on whose shores the Terraces were situated. The eruption produced a row of deep craters along this line, and these are separated by a series of bridges or partitions, some of which are quite sharp and thin at the top, and others are several hundred yards in breadth. The accompanying map, taken from accurate surveys by Mr S. Percy Smith, F.R.G.S., shows the line of the great fissure and the craters along its course. (Plate X.).

The sides of the chasm reveal an interesting section of the mountain, which is seen to be made up of cream-coloured rhyolite lava beneath, with deep red or dark grey stratified ash-beds at the top, and here and there a dark, slaggy patch of the new lava plastered on to the side, or lying like a saddle on the back of the separating bridges. With the exception of these isolated splashes, there is no sign of any lava stream among the products of the eruption. The eruption produced nothing but ashes and scoriæ, and this is to be explained by the fact that there was so much water present that the molten rock beneath was blown to fragments by the sudden expansion of the steam imprisoned in its pores before ever it rose to the edge of the craters. There was, no doubt, lava at a certain depth, and some of it can be seen in the bottom of the deeper craters, and the fact of its existence proves that a true volcanic eruption took place, and that the explosion was not due merely to the pressure of highly-heated steam. Small volcanoes are sometimes produced by steam explosions, but in such cases the materials thrown out are found to be composed of shattered fragments of the rock beneath, unaccompanied by matter of a genuine eruptive character.

The eruption of Tarawera did not last long—only about five or six hours—but while it lasted the explosion was one of tremendous energy. A long row of craters, some of them over 800 feet in depth, were blown out of the solid rock, and from these was ejected a shower of stones, mud, and ashes, estimated by Professor Thomas to have a bulk of 1,960,000,000 cubic yards, or nearly two-fifths of a cubic mile. The ash fell over an area of more than 6000 square miles on land, and a good deal was carried away seawards by the south-west wind, to fall into the Bay of Plenty.

The observations of Mr Percy Smith, Assistant Surveyor-General, who has from time to time published very accurate maps and reports on the volcano and its surroundings, show that the effect of the accumulation of ash was to raise the summit of Tarawera to 3770 feet, which is 164 feet above its original altitude.

The most important change in the topography of the district

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is the formation of the new Lake Rotomahana at the western base of the mountain, and about half a mile south from the nearest part of Lake Tarawera. The general appearance of the new lake is shown on the accompanying topographic sketch, and on the right a small part of the Tarawera lake comes within the view. The crater lake of Rotomahana has steep sides, and covers the hollow in which were situated the small Lake Rotomakariri, and the larger hot lake Rotomahana, whose shores were adorned by the terrace formations. The surplus waters overflowed into Lake Tarawera by a small stream which has been obliterated by the eruption.[1] During the explosion the lake was entirely blown up, and a huge hole formed with a small pool in the bottom about 400 feet below its original surface. The line of the great fissure (shown on the map) ran straight through the top of Mount Tarawera and the bed of Lake Rotomahana, and a row of craters mark its course across the country. Another crater lake further along the line of the chasm, and close to the foot of the mountain, was produced at the same time, and was named Rotomakariri, after the original tarn of that name. Both lakes have gradually been filling up, and now, instead of together occupying an area of about twenty-five acres, which they did in August 1886, they have joined into one imposing sheet of water, three miles in length, 5600 acres or more in extent. The level of the water was found, from surveys made in 1893, to have risen 420 feet during eight years, and at the time of my visit in 1895 it had crept up still further, and covered up some of the features shown on Mr Percy Smith's map published in 1894. When it rises to 1080 feet above sea-level, or 95 feet above its level in 1893, it will either find a subterranean outlet through the porous soil, or it will overflow the ashy ridge, and again find an outlet to Lake Tarawera. A channel in the soft scoriæ will again be excavated, by which a considerable part of the water will be drawn off, and the surface of the lake will, after reaching a maximum, begin to decrease in area, leaving no doubt a small notch or terrace round its margin to show the line of high-water mark.

The accompanying topographic sketch from near the top of Tarawera shows the appearance of Lake Rotomahana and the country to the west and south on the 27th September 1895. The day was happily very clear, and we were fortunate in catching a glimpse of the top of Ngauruhoe and Tongariro, about ninety miles off on the south-western horizon; and as the clouds lifted for a few minutes, the steam issuing from the cone of Ngauruhoe (7841 feet) was distinctly visible.

[1] These original topographical features are shown in red lines on the map of Tarawera. (Plate X.)

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VIEW SOUTH-WESTWARD FROM MOUNT TARAWERA, SHOWING THE NEW LAKE ROTOMAHANA.

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A sharp pointed rock, known as the Pinnacle, formed a prominent landmark on the north or right side of the Rotomahana crater after the eruption. As the water rose, the Pinnacle became an island, and gradually diminished in size until nothing but the tip appeared above water. This was shown on Mr Percy Smith's panorama, taken in 1893, and published along with his latest report in the following year, and at the time of my visit the continued rise of the lake was clearly proved by the diminished size of the Pinnacle, which is shown on the sketch as a mere speck, and may by this time have completely disappeared. The Pinnacle was close to the White Terrace and near the head of the Kaiwaka stream, by which the old Lake Rotomahana overflowed into Lake Tarawera. The course of this stream is still marked approximately by the storm channel shown on the sketch.

The view north-eastwards along the volcanic belt was equally clear. The following sketch gives a glimpse of the Tarawera chasm and the craters and bridges between them, and on the horizon on the left is seen, far out to sea in the Bay of Plenty, the great fumarole of White Island, seventy miles distant, from which clouds of steam are constantly rising. The panorama from Mount Tarawera thus embraced a distance of 160 miles, and included the entire length of the volcanic zone, between whose extremes nearly all the curiosities of the New Zealand Wonderland are to be seen.

Reference has been made in this paper to the Yellowstone National Park, and nobody who has seen the "wonderlands" of both New Zealand and the United States can resist making comparisons between the kindred phenomena of these two volcanic regions. The phase of declining volcanic activity indicated by hot springs, solfataras, fumaroles, and mud volcanoes, is only a temporary episode in the history of an old volcanic area, and but few places are known to us which are passing through this phase at present. Geyser action in the Yellowstone is evidently on the decline, and even within the last twenty-five years several of the geysers and hot springs have notably decreased in power, while all the volcanoes have been extinct for many centuries. The geysers of the Yellowstone are more powerful than those of New Zealand, and since the destruction of the Terraces of Rotomahana, the "Minerva Terrace" (Plate VIII.) at the Mammoth Hot Springs, with its exquisite ornate cups and basins, is probably finer than anything that has been discovered of its kind elsewhere. The Terraces of New Zealand were precisely similar to, but far more magnificent than, those of the Yellowstone Park. Fortunately we have ample descriptions and photographs of the lost Terraces, and I

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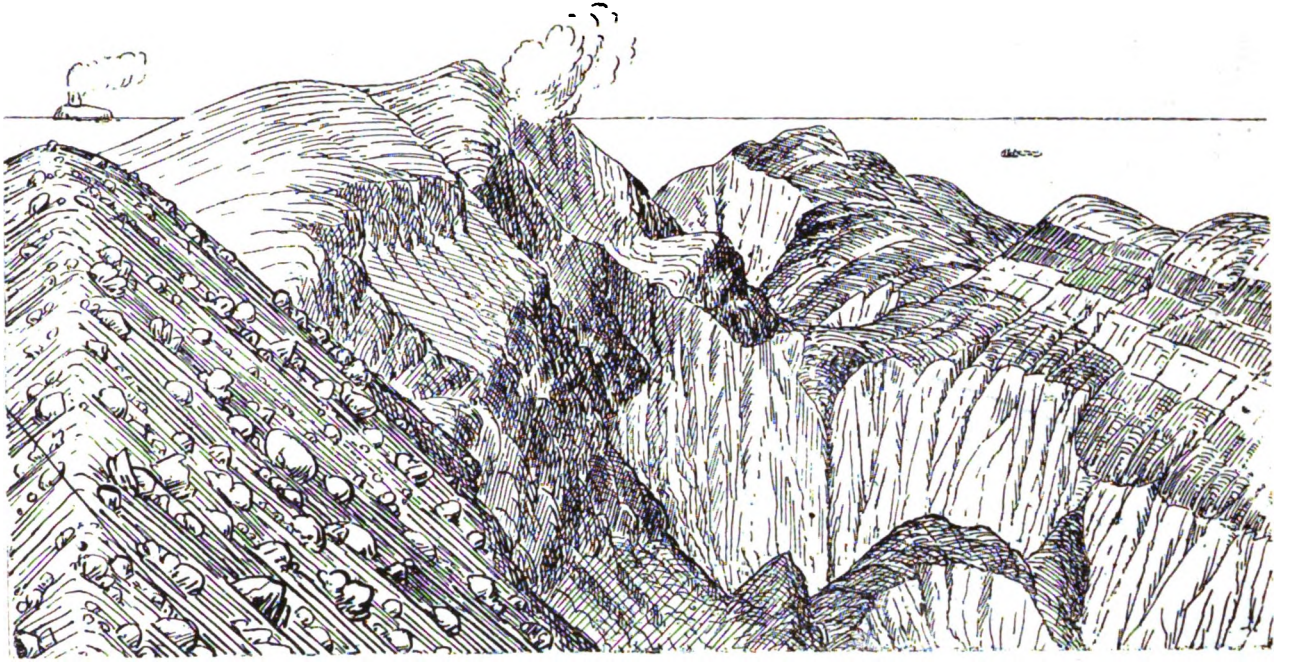

VIEW NORTH-EASTWARD FROM THE EDGE OF THE TARAWERA CHASM.

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obtained several views taken by Mr J. Martin, F.G.S., of Auckland, from some of which the accompanying illustrations are reproduced. Mr Martin was engaged with his camera on the 22nd November 1885 at the White Terrace, when suddenly the geyser at the summit burst forth in an eruption of unprecedented violence. The steam ascended in a column five times as high as the cliffs above the basin, and as these are 200 feet in height the altitude of the pillar of cloud must have been at least 1000 feet. Mr Martin told me he was successful in getting a photograph of the eruption, but his camera was not large enough to take in the whole of the vast column of steam. The accompanying block (Plate VI.) is a very poor reproduction of this photo. of one of the premonitory signs of the explosion of Tarawera seven months later. The photo. of the "White Terrace Cups" (Plate VII.) is from another of Mr Martin's plates, and the exquisite sinter formation so clearly represented here is identical in configuration with many parts of the Mammoth Hot Springs geyser deposits of the Yellowstone. For purposes of comparison, a photo. of the Minerva Terrace at the Mammoth Hot Springs is appended. (Plate VIII..)

The New Zealand volcanic zone, whose outline is indicated on the accompanying map (Plate IX.), also abounds in sulphur deposits of brilliant hue, and seething mud holes of awesome aspect, whose dark and viscid contents are constantly bubbling and spluttering like thick soup or porridge in a pot. At many places the mud is so thick that it has been built up into conical mounds with steaming craters at the top, which resemble diminutive volcanoes of the most weird and grotesque appearance. Mud volcanoes and "paint pots" of white or coloured clay are also common in the Yellowstone Park, but in number and size their New Zealand relatives far surpass them. One of the largest I noticed had the size and shape of a hayrick. It was 12 or more feet in height, and consisted of dark slate-coloured clay, with a shallow crater on the top in which the viscid fluid was bubbling languidly, as if the fire had gone low and the water was about to go "off the boil." In other cases the fire had gone quite out, and the extinct mud volcano was represented by a dirty mound in the midst of the ti-tree bush, soon to be worn away by denudation and obliterated by the rapid growth of vegetation.

These and many other manifestations of the proximity of the subterranean fires make "Infernal New Zealand" a place of unusual interest to the physical geologist. The sudden and terrible eruption of Tarawera shows, however, that the region is in a state of more or less unstable equilibrium, and another explosion might at any time take place between Tarawera and the Taupo district.

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XXVII.—*Notes on the Minerals of the Hilderston Silver Mines, Linlithgow.* By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., Curator of the Collections of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art.

(Read 7th May 1896.)

CONSIDERABLE interest is felt by both geologists and mineralogists in regard to the geological position and mode of occurrence of the "Silver Ore" in this oft-described locality. On the Geological Survey map, Sheet 31, the mine is shown, by three short gilded lines, about two miles NNE. of Bathgate, and near one of the highest points of the Bathgate hills. Its geological position is in the upper part of the Lower Carboniferous Rocks in connection with a series of basalt lavas and tuffs, which occur interstratified with marine limestones, charged with numerous specimens of *Productus giganteus*. This fossil is now generally recognised as being confined, all over Western Europe, to the limestones near the base of the Yoredale Rocks, to which horizon, therefore, the Hurlet or Main Limestone of the Bathgate hills, in which the silver mine is situated, must henceforth be referred. One or two small dykes are intruded into the rocks adjoining the veins. These latter appear to be fissure veins, which probably coincide with faults of no great magnitude.

The minerals themselves may be noticed under two heads. The first of these comprises those which, not being original constituents of the rock, yet occur in noticeable quantity around the veins. Of these the only ones calling for any special remark are some fine crystals of Calcite, chiefly of the form *e*; and besides this, somewhat extensive deposits of Dolomite. This latter occurs as a replacement-product of part of the limestone, and may be referred to the infiltration of magnesian solutions derived either from the decomposition of the ferromagnesian silicates in the associated lavas, or else from solutions of the same composition which have percolated downward from the New Red Rocks, which there is reason to believe formerly extended over the Carboniferous Rocks of that part, and have left their mark in the shape of red-stained sandstones and ferrified and dolomitised limestones, over so much of the central and southern parts of Scotland.

Under the second heading comes the minerals which occur in the vein itself. The principal vein-mineral is Barytes, which occurs in both the massive form and in its very common condition of sheaves of thin tabular crystals. No crystalline forms specially worth mentioning appear hitherto to have been met with in these mines.

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Associated with the vein-breccia in which the Barytes occurs are small scattered nests and crystalline masses of Galena. From these Mr James Currie recently obtained some well-crystallised combinations of the cube and the octahedron.

Galena very commonly contains a percentage—usually variable, and but rarely very high—of silver, which is supposed to exist in the galena as a solid solution, and to consist, like its solvent, of a sulphide. On the occasion of the recent visit of the Geological Societies of Edinburgh and Glasgow to the Hilderston Mine, the party were informed by Mr Henry Aitken of Falkirk, who courteously showed them over the mine, that part of the galena at present being won from the mine contains but a very small percentage of silver. But if we can credit ancient records relating to this mine the case in past times must have been very different.

To students of mineralogy, however, the chief interest of the mine as it stands at the present day is of a different nature. This is the case, because, associated with the galena before-mentioned, there occurs a quantity of Niccolite or nickel arsenide, which is not known to occur at more than three or four other localities in Scotland. These, it may be mentioned, are Achna-Gonolan, Inverness; Edintien, Blair-Athol; Cassencary, Kirkcudbright; and West Groove, Wanlockhead. A remarkably fine specimen of the Niccolite from Hilderston Mines has lately been presented to the collection of Scottish minerals in the Edinburgh Museum by W. Drummond, Esq., W.S. Others from the localities above-mentioned have been presented by Dr Heddle and a few other donors.

Associated with the Niccolite of the Hilderston mines occurs another ore of nickel, its hydrated arsenate, Annabergite, $Ni_2(AsO_4)\cdot 8H_2O$. This occurs as a pale-green, earthy encrustation, and has doubtless originated through the oxydation and hydration of the nickel arsenide by the action of percolating waters from the surface.

Nickel compounds are so very commonly found in association with compounds of Cobalt that the occurrence of some of these latter at Hilderston might reasonably have been expected. Little surprise, therefore, was felt when one member of the party above-mentioned, Mr George L. Craig, of Edinburgh, after a visit to the bottom of the present workings at Hilderston, brought up a specimen of ore coated with a peculiar pink, chalky-looking encrustation, which, in appearance, may be well likened to a common form of dentrifice. On examination of this pinkish encrustation the writer of this note identified Mr George Craig's specimen with Erythrite, the hydrated arsenate of cobalt, which had previously been recorded from this mine and from only one other Scottish locality, Cassencary in Kirkcudbrightshire.

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XXVIII.—*Desert Conditions in Britain. An Address to the Geological Society of Edinburgh, at their Opening Meeting on the 19th November* 1896.[1] By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., F.Z.S., Curator of the Collections of Scottish Geology and Mineralogy, Edinburgh Museum of Science and Art, *Vice-President.* (Plate XI.)

IT has long been recognised by geologists that, amongst the geographical mutations which all parts of the earth's surface have at one time or another undergone, the change from humid to arid climatal conditions has several times had a place. It has now and then happened in past times, even in Britain, that conditions of the normal kind, as regards rainfall, have subsequently given place for a time to true desert conditions, differing in no essential respect from those prevailing in many arid regions at the present day.

By desert conditions, as here understood, is meant that combination of geographical conditions which has led to certain parts of the earth's surface receiving a smaller annual precipitation than suffices for the maintenance of any types of vegetation except those specially adapted by evolution to an environment in which aridity is the dominant feature. As typical examples of the conditions referred to may be cited the Sinaitic Peninsular, parts of Afghanistan, the great Central Asian deserts, as well as the more arid parts of western North and South America. As regards *temperature* these regions widely differ from each other; whence it will be seen that the prevalence of excessive sun-heat is by no means a special characteristic of desert regions.

In one respect all areas of Inland Drainage may be regarded as areas where desert conditions prevail. Under the existing geographical conditions of the earth's surface the areas of inland drainage occupy an area 11,486,350 square miles,[2] which, as the area of land draining into the ocean is estimated[3] at 44,211,050 square miles, makes the proportional area of the one to the other as about as one to four. Dr Murray gives as the total

[1] The same Address was also given as the Inaugural Address to the Philosophical Society of St Andrews, and afterwards before the Geological Society of Glasgow.

[2] Dr John Murray, Roy. Scot. Geog. Mag., vol. iii. p. 75. [3] *Loc. cit.*

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area of the ocean 141,243,300 square miles. The area of inland drainage is to the area of oceanic drainage, therefore, about as one to fourteen. If we assume that the various geographical conditions of the earth's surface in the past periods of its history were, taking one time with another, combined in much the same proportion to each other as they are now, then on this assumption we might expect to find records of marine conditions amongst ancient rocks from twelve to fifteen times as frequently as we should records of conditions of inland drainage. As a matter of observation, this is about the proportion which the rocks formed under conditions of inland drainage bear to those formed in the sea.

Dr Murray defines Desert Conditions as those which prevail where the annual rainfall does not exceed 10 inches. Dr Murray's figures (*op. cit.*, p. 74), give as the area where these climatal conditions prevail 12,214,250 square miles. I should be disposed to modify this definition to a certain extent, and to include under areas of Desert Conditions all those areas where the total quantity of aqueous vapour, normally present in the air, is much below the average. These conditions may prevail where the rainfall exceeds 10 inches; for it may happen that the total quantity of rain precipitated during occasional thunderstorms may amount to considerably more than that, and yet periods of several months, and even years, may elapse without more than an occasional shower, quite insufficient for the needs of vegetation. Arid conditions of this nature are usually due to the fact that the regions where they prevail lie inland in relation to great mountain areas, over which the chief moisture-bearing winds have passed. Such upland areas act as condensers, and wring every available drop of moisture out of the clouds that pass over them, leaving little or none to be transported to the areas on their lee side.

Two results of considerable geological importance result from arid conditions of the kind under notice. Firstly, in a region where the rainfall is either low or very irregular in its occurrence, vegetation of almost every kind fails to retain a permanent footing. As a consequence, sooner or later, large tracts of country, which under normal conditions of climate would be covered with soil, speedily become bare and tend to remain in that condition: animal life, also, tends to be but poorly represented. Secondly, in a region where the percentage of aqueous vapour present in the air is below the normal, both insolation and radiation attain to much higher extremes. It is a well-known fact that the presence of aqueous vapour in the air tends to act as a screen to the sun's rays during the day, thereby very materially tempering their effect upon rock surfaces, and tends

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equally to act as a blanket by night, checking the radiation to a very important extent. Where the amount of moisture present in the atmosphere is but small, the sun's rays exert their maximum power, and heat up the rock-surfaces to their fullest extent within a comparatively short time. In like manner the absence of the blanket formed by moist air permits of the rocks cooling down with equal rapidity to a very low point. In arid tropical regions, rocks, stones, and sand, heat up by about 2 P.M. to temperatures so high that the hand can scarcely bear to touch them; while by about 3 A.M. the air in contact with these same rocks may be at or below the freezing point. In arid regions situated within the temperate zones, the effects of insolation and radiation are hardly less marked, and the diurnal range of temperature to which the rocks are subjected is considerably greater there than that which can possibly obtain in more humid regions.

In Walther's "Die Denudation in der Wüste und ihrer Geologischen Bedeutung," the chapter devoted to the diurnal range of temperature in Egypt and the parts adjoining is full of interest in this respect (see p. 359 *et seq.*). Not to enter into details here, it may suffice to point out some of the consequences of geological interest which arise from such an excessive diurnal range. In Britain and other countries where humid conditions prevail, the expansion of rocks caused by sun-heat during the day does not as a rule proceed beyond the mean, and the rise of temperature and the consequent expansion of the rocks takes place gradually. In like manner the fall of temperature and the consequent diminution of volume of the rocks is also moderate, and takes place nearly always at a slow rate. Consequently the effects of insolation and radiation are with us factors in denudation of no more than secondary importance. They are certainly of much inferior importance as factors in denudation to the effect of such chemical causes as the solvent action of rain water charged with the humus acids, and their ultimate term carbonic acid. The difference between arid and humid conditions, especially where limestones and rocks of eruptive origin are concerned, is most marked and important. In the one case the extreme diurnal range of temperature, which may amount to 130° Fahrenheit, splinters and shatters the rocks into angular fragments (some of which may be of several tons in weight), at the same time leaving them almost entirely unaffected by any changes of a chemical nature. In the other case, that of denudation under humid conditions, the waste of the rock is chiefly accomplished by means of chemical changes; the mechanical effects are usually quite subordinate to those which have been termed decomposition. Limestones in arid districts splinter off

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from the parent mass in angular blocks, which shew no sign of chemical erosion. Under humid conditions the same rock presents abundant evidence of being fretted and corroded by the acidulated waters, whose action ends only in the entire solution of the rock and its transportal seawards as bicarbonate. Eruptive rocks under humid conditions disintegrate chiefly by the decay of their felspars, from which the alkalies are removed in solution, combined with CO_2. Under arid conditions these rocks splinter off in angular fragments, whose constituents, and especially whose felspars remain quite fresh, and not in the least kaolinised.

Another factor of importance in the present connection relates to the structure of eruptive masses. These, of course, consist of usually three or more crystalline silicates, together with, in some cases, an interstitial ground mass. Supposing, for argument's sake, that these minerals are felspars of two kinds, quartz, and hornblende, we have a rock whose constituents are different not only in their composition but also in their physical properties. Their specific heats are different, so that under a given temperature they warm (or cool) unequally in a given time. Their rates of expansion for a given rise of temperature are not only different amongst themselves, but are different in different directions for each crystal. Hence, with a rapid change of temperature every twenty-four hours, the unequal expansion and contraction not only loosens the cohesion of the several minerals to their neighbouring minerals adjoining, but, in the case of the hornblende, tends to splinter the individual crystals into fine slender threads, which are easily removed from the wasting rock even by a gentle breeze. The felspars split along their dominant cleavage planes, and fall away from the rock, retaining, however, their faces as bright and fresh as if they had been newly hammered out of a perfectly sound piece of rock. No such freshness or angularity of felspar fragments is possible as a result of weathering under humid conditions.

Thus it arises that, in arid regions, eruptive rocks waste in a totally different fashion from what they do in humid areas. Their ferro-magnesian silicates disintegrate under insolation, and are blown away by the wind. Their felspars break up into fresh and perfectly angular fragments, which, as screes, slide down the mountain sides in the direction of the bottom of the valleys. The quartz, simply detached from its matrix, suffers, at the most, but a mechanical reduction in size. In course of time an occasional thunderstorm bursts over the area, the screes are washed to the bottom of the valley or wady, and are there levelled out by the temporary flood. Then follows a period of

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drought, during which the wind takes up the work of deposition, and spreads out more or less horizontal layers of finer material over the torrent débris just before brought down. In this way well-stratified alternations of arkose and finer rock material, largely consisting of sand, are being formed in the wadys of desert areas of the present day.

The prevalent tendency of desert denudation is to reduce the inequalities of the surface and not to create valleys. Wadys, therefore, are in all cases the effect of running water, and must have been formed under climatal conditions of a normal or humid character, which formerly prevailed where these now occur.

Excellent examples of the phenomena referred to are to be seen in the Sinaitic Peninsula.[1] In that area the Nubian Sandstone, &c., formerly overspread a nearly level tract formed of gneisses and granitoid rocks. These, subsequently upheaved into great plateaux, were for a long time exposed to the denuding action of rain and rivers, when humid conditions prevailed in that area. Deep and wide valleys were thus excavated. Then came a gradual change, which ended in replacing humid conditions by arid, and in the formation of deserts. The rocks no longer weather in their former fashion, but splinter up under the alternate expansion and contraction due to the high diurnal range of temperature. Angular quartz grains and angular pieces of perfectly fresh felspar are now detached from the mountain sides, while the dark mica and the hornblende blow away as fine black dust. Screes accumulate on the sides of the wadys until one of the occasional torrential rains descends upon them, when they are transported to the bottom of the wady as torrent débris, and are spread out by the floods in rudely parallel layers, over which afterwards dunes are drifted, and eventually levelled out. I shall endeavour to show in the concluding part of this address that conditions very similar to these have more than once or twice obtained within the limits of what are now the British Isles.

In a region where the rainfall is low it not uncommonly happens that the wind assumes an importance as an agent of both denudation and deposition far greater than it does in humid climates like our own. Large quantities of the finer material, loosened by insolation, are drifted far and wide by the winds, abrading rock surfaces as they are driven past them in such a fashion as to produce very remarkable surface features.

[1] An extensive series of photographic views of these was projected by the limelight in illustration of this when the present address was delivered.

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Some examples of these are figured by Walther in the work above mentioned. (I have long taught in my geology courses that the first rough shaping of the Sphinx itself was due to the long-continued action of this natural sandblast.) Good examples on a small scale, from British localities, are exhibited in the Geological Index Collection in the Gallery of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art. Erosion by means of blown sand not only files and rasps away rock surfaces in a fashion different from that produced by any other natural agency, but the sand grains themselves, as well as the material acted upon, are polished, smoothed, pitted, and rounded, in a manner peculiar to this mode of erosion. As the means by which this is accomplished have considerable geological interest, and are not commonly understood, I will devote a few lines to such explanation as may be necessary:—

In the shaping of sand grains in general three principal factors are concerned. These are—(1) Solar energy, which sets the wind and the waves to work; (2) Gravitational Energy, which acts in opposition to the energy directly emanating from the sun; (3) Surface Tension, a form of energy which in the present connection is of especial interest and importance. Solar heat distils aqueous vapour from the broad surface of the ocean, winds drift it landward, where it is chilled and condensed into rain or snow, finally descending under the action of gravitation from the level to which it had been lifted by the sun's energy back again to the level of the sea. Flowing downhill in obedience to the force of gravitation, it transports seawards rock fragments of various kinds, gradually reducing these to successively smaller fragments as it proceeds from higher to lower levels. In order to understand the bearing of this upon the subject of the present address, we must first consider the principles which determine the ratio between the superficial area and the volume (and therefore the weight) of a stone which is undergoing reduction in size under the joint action of gravitation and the forces that work with, or act against, that form of energy.

The *surfaces* of bodies of similar figure, but different in size, vary as the square of their linear dimensions. For example, the surface of a cube 1 inch by the side presents an area of 6 square inches, while that of a sphere of the same diameter is 3·14159 (&c.) square inches. If the linear dimension of the cube be doubled, its surface area is increased in the proportion of $2 \times 2 \times 6$, *i.e.*, 24 square inches; while the same increase in the case of the sphere augments its superficial area in the proportion of $2 \times 2 \times 3{\cdot}1416$, *i.e.*, 12·566 square inches. If the one-inch cube be reduced to a cube half-an-inch by the side, its

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surface area is diminished from 6 square inches to an area of an inch and a half. A sphere with a diameter of 1 inch has a surface area of 3·14159 square inches; while if it be reduced to half that diameter its surface area will diminish to ·78539 of a square inch.

But in the case of *volumes* of bodies with similar figure that differ in size, it is well-known that these volumes increase as the cube (or decrease as the cube root) of their respective linear dimensions. A spherical stone 1 inch in diameter has a volume of ·5236 of a cubic inch (and a surface area of 3·1416 square inches); but if that stone be worn down from a diameter of 1 inch to that of ½ an inch, its volume is diminished to ·06545 of a cubic inch (its surface area, as already mentioned, being ·78539 of a square inch.) This is one way of stating the fact that bodies of similar figure, with enlargement of dimensions, increase in volume, and therefore in weight, much faster than they increase in surface; or that, with reduction of dimensions, they decrease in volume, and therefore in weight, faster than they decrease in superficial extent. To put this into simpler language, one may say that, when a grain of sand is being worn down, its surface area does not lessen so fast as its weight does, but becomes proportionately larger; in fact, with each halving of the diameter of a sphere the ratio of its surface area to its weight is doubled. A quotation from Sorby's address may be added here to illustrate one of the applications of this principle (Q.J.G.S., xxxvi., pp. 32-3): "The friction [of a sand grain [1]] upon the bottom must be always small . . . and must vary as the weight, and therefore as the cube of the diameter; but the surface from which the material must be worn [or which the grain presents to the fluid] varies as the square of the diameter. Hence, even making no allowance for the extra buoying-up of very minute particles by a current of water, depending upon surface cohesion [now called Surface Tension], the effect of wearing on the form of sand grains must vary directly as their diameter or thereabouts. If so, a grain $\frac{1}{10}$ of an inch in diameter will be worn ten times as much as one $\frac{1}{100}$ of an inch in diameter, and at least a hundred times as much as one $\frac{1}{1000}$ of an inch in diameter. . . . A grain $\frac{1}{10}$ of an inch in diameter would be worn as much in drifting a mile as one $\frac{1}{1000}$ of an inch in being drifted 100 miles."

We may now pass on to consider this form of energy, which is here referred to as Surface Tension. This is as yet somewhat imperfectly understood; but some idea of its general nature may be gathered by studying the phenomena that often accompany the pouring of fluids out of earthenware vessels provided with lips or spouts. Pouring tea out of a glazed earthenware tea-

[1] My own remarks are added in square brackets.

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pot shews this in many cases remarkably well. In the hands of those not accustomed to perform this household duty, the tea which is meant to fall in a graceful curve from the spout into the tea-cup, will, instead of doing so, persist in running a variable distance along the underside of the spout, whence it eventually drips off from the vessel at a point far removed from that which was either expected or desired. A study of this homely illustration will enable us to realise the fact that there are evidently in this case two independent sets of forces at work: gravitation (if it be not interfered with) tends to make the tea drop perpendicularly from the end of the spout; while some other force of a different kind is evidently counteracting that of gravitation, and is tending to make the tea adhere to the surface of the glazed earthenware, and so to remain in contact with the teapot as long as possible. This force is that of Surface Tension. The course taken by the fluid is readily seen to be one compounded of motions arising from the joint action of gravitation, surface tension, and the impulse given at the outset by the operator.

Surface Tension, illustrated by this example, operates in nature in a great variety of ways, acting, indeed, between every fluid and any solid with which that fluid may be in contact. The results differ very materially, according to the respective natures of both the fluid and the solid. They differ in the case of the contact of the same fluid with different solids, and in that of the same solid in contact with different fluids. Moreover, in the operation of natural causes, the effect is further complicated by the ratio which the bottom velocity of the transporting medium bears to the superficial area, the weight, and the durability, of the material operated upon, as well as, of course, upon the distance the particles travel, or the time during which the forces act. Much valuable information upon these heads is given in Sorby's Presidential Address to the Geological Society of London (Q.J.G.S., vol. xxxvi., p. 32.) See also Daubree's *Géologie Experimental*, and J. A. Phillip's "On the Physical History of Grits and Sandstones" (Q.J.G.S.).

It follows from these considerations that, in the process of wearing down a grain of sand by friction on the bottom, under the impulse imparted by fluids in motion, surface tension becomes more and more effective in proportion as the surface area of the grain increases relatively to the weight. Eventually a stage of reduction is reached at which the adhesion between the moving fluid and the grain is sufficient to counteract the opposing effect of gravitation. When that is the case the grain is buoyed up by the fluid and carried forward as if it were part of the fluid itself. After this, further rounding of that grain in

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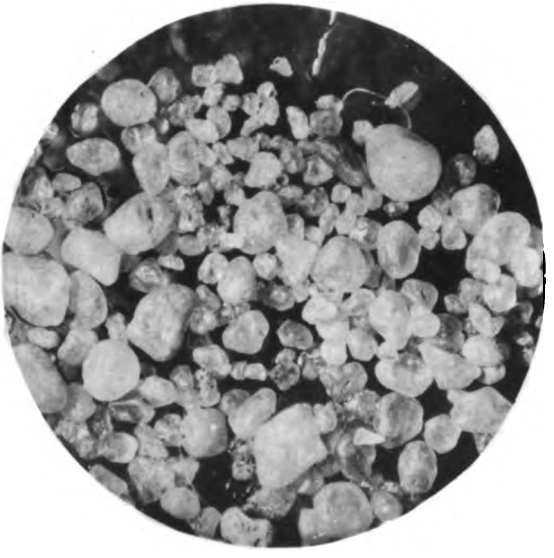

Fig. 1. (× 10)
Desert Sand, from near Cairo.

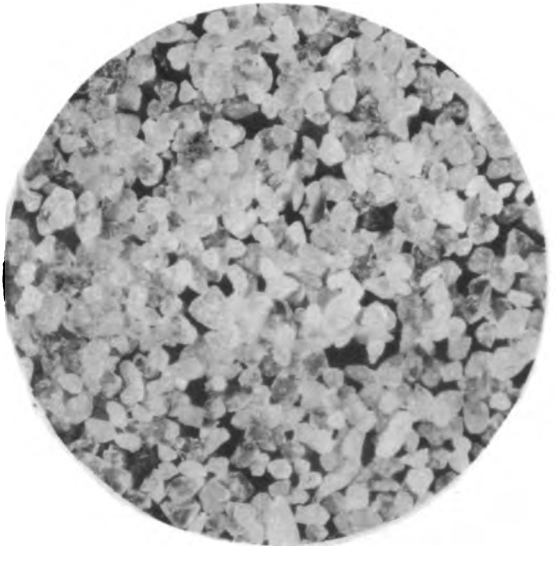

Fig. 2. (× 10)
Sea Sand ("Musical Sand") from Lairg Bay, Eigg.

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that particular medium is no longer possible. Hence the grains of sand which have been shaped as such in either sea-water or river-water undergo no further rounding after they have been reduced below certain dimensions, which are determined by the factors above mentioned.

[It should be mentioned here that this latter aspect of the subject under notice was most admirably set forth by Professor Heddle of St Andrews in an address on "Sand," delivered before the Edinburgh Field Naturalists in 1896. The writer is indebted to Dr Heddle for many additions to his geological knowledge in this and other directions.]

Like water, air is a fluid, and there is exerted between a given sand-grain and the atmospheric air surrounding it a certain amount of surface tension too. But this is very much lower than it is in the case of water; consequently gravitation in this case acts with more effect. This is another way of stating the fact that a sand grain impelled by the air will tend to be rolled against other sand grains, and bowled along in contact with rock surfaces long after its size has been reduced to that of the smallest which the action of water of any kind can possibly round. Given, therefore, sufficient time, and wind is capable of reducing sand grains of almost all sizes into a more or a less spherical form by prolonged friction against each other and against surfaces of rock. As a matter of fact this is exactly what does happen. The long-continued rolling and drifting to which desert sands have been subjected ends by shaping a large proportion of the sand grains into smaller spheres. The spherical form of the grains and their pitted and polished surface are thus distinctive characteristics of desert sands. (This was well illustrated by photomicrographs of sea-sand and desert-sand exhibited when this Address was delivered, see Plate XI.)

Putting this statement into another form, we may conclude with a tolerable amount of certainty that any sandstone largely composed of well-rounded grains of sand, represents a desert sand, and was formed under arid conditions, on a land surface. We shall presently see that abundant confirmation of the correctness of this inference is afforded by other sets of facts, to which reference will presently be made.

One of the characteristic modes of accumulation of desert sands is in the form of dunes, which are often of considerable size. Their longer axes are said to range, in a great many cases, north and south, as if determined by the earth's rotation. False bedding at exceptionally-high angles is another characteristic of desert sands; and it is said that the dominant direction of these planes inclines from the east westward, as if, again, the earth's rotation had something to do with it. Ripple marks are of very

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common occurrence in recent desert sands. It is said that these may be distinguished from ripples formed under subaqueous conditions, by the fact that in the desert sand ripples, the coarsest grains occupy the *crests* of the ripples instead of lying in the troughs. This feature has not yet been investigated in connection with the fossil desert sands, to which special reference will presently be made.

Rock material accumulated under desert conditions at any period of the earth's history may be expected to exhibit some, or all, of the features above described, if we are correct in assuming that geographical conditions prevailing in former times were not essentially different from those met with now. Screes and torrential deposits of angular and quite unweathered rock materials, subsequently compacted into arkoses and breccias, will be found in co-existence with strongly false-bedded sands, whose component grains will show abundant evidence of long-continued rolling under sub-aerial conditions. These deposits, as a whole, will be found to occur in old wadys, or to lie upon exceptionally-irregular surfaces of rock, in which respect desert-formed rocks contrast very strongly with strata laid down under normal marine conditions.

Such deposits as these, which are chiefly sub-aerial in origin, may co-exist, even in desert areas, with deposits formed in comparatively shallow lakes or Schotts. Into such lakes desert sand is transported by the wind in large quantities. Furthermore, rivers of small volume discharge into these shallow lakes water whose matters in solution have already been partially concentrated by evaporation under arid conditions. Amongst the substances carried down in solution by rivers in all parts of the world are some few that merit special consideration in the present connection. The principal of these are—(1) Chloride of Sodium, which, carried up into the air in the form of sea spray during storms, is drifted inland, forms the nuclei of rain-drops, and thence descends to the land. Under ordinary circumstances this Chloride of Sodium completes the cycle by flowing back in rivers to the sea; but under desert conditions the aqueous medium in which it is dissolved is returned to the clouds by evaporation, while the salt is left behind, to accumulate until its precipitating point is reached. (2) Other sea salts, especially Magnesium Chloride. (3) Carbonate of Lime, Magnesia, Iron, etc., dissolved from the rocks of the land by the humic and allied acids and carbonic acid. With these are various sulphates, as of lime, iron, etc., also derived from the land drained by the feeders of the lake. In addition to the substances carried down in solu-

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tion are the remains of animals and plants drifted down in suspension. The proportion in which these will occur is, of course, largely determined by the nature of the climatal conditions prevailing within the basin of the rivers draining into the lake. Into the Dead Sea, for example, large quantities of vegetable matter are annually transported by the Jordan. The same is true of fishes and other forms of animal life. It will presently be shown that these organic substances exercise very important influences upon the nature of the chemical deposits taking place under these conditions.

In regard to the history of rock-salt, gypsum, dolomite, and their associates, which have been found under conditions arising from those under notice, I do not propose to dwell in this Address. But in dealing with the evidences of desert conditions in the past, there are three substances which afford important evidence in relation to the history of British rocks. These are Magnesia, Iron, and the Bituminoids. Probably, in the first instance, the two first-named (like lime) have primarily originated from the decay of eruptive rocks. Under normal, humid, or pluvial conditions, these substances find their way to the sea in the form of bicarbonates, which state they reach through the solvent action upon rocks of water charged with CO_2 and the allied humic acids already referred to. But in areas of inland drainage, where the whole of the water carried down by rivers is dissipated by evaporation, these substances in solution are left on the spot, and gradually accumulate (like the salt, gypsum, and dolomite), until their respective points of precipitation are reached, when they are thrown down in the solid form. In the case of such areas of inland drainage some of the carbonate of magnesia either becomes converted on the spot into dolomite, through combination with carbonate of lime, or else it soaks down through the porous strata in which the lake is situated. On meeting with any calcareous matter, even in the solid form, it at once enters into combination with it, and finishes by converting part or the whole of the carbonate of lime into dolomite. This is one very characteristic feature connected with these deposits formed in inland lakes. It is one of considerable importance in the present enquiry, as I have repeatedly pointed out on former occasions to this Society and others.

The history of the ferrous carbonate has been dealt with by Mr Hudleston in his Presidential Address to the Geologists' Association (vol. xi. No. 3, p. 104.) His summary of the chief points of interest leaves almost nothing unsaid with which a geologist is interested. I therefore give part of it here nearly in the author's own words. This part is enclosed within square brackets:—

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[Iron, liberated from eruptive rocks, is carried away in solution as *bicarbonate*, which is disseminated through the waters of the lake. The part next the surface seizes upon an additional molecule of oxygen in the proportion of F_2O_3. This causes it to lose its carbonic acid; but the ferric oxide thus formed immediately combines with water to form the ferric hydrate, and then sinks to the bottom. Portions of such accumulations are from time to time re-dissolved, owing to the abstraction of the extra molecule of oxygen by the carbon of *decaying vegetation*. This extra molecule of oxygen helps to form the CO_2, or other humus compounds, which dissolve the iron, now reduced to the protoxide. In this way the game of solution and precipitation is kept up indefinitely, and where the balance is in favour of precipitation an accumulation of iron ore will occur. Reduction renders iron soluble and locomotive; oxygenation arrests locomotion and fixes the iron on the spot. Iron is a base, with a strong affinity for the humus acids, and their ultimate term Carbonic Acid. It has also a strong affinity for oxygen, and in the presence of this it forms the nearly indestructible (and, in the *absence of organic matter*), almost insoluble, ferric oxide.

As ferric oxide in the *presence of organic matter*, it provides the oxygen for decay, and its residuary protoxide is itself dissolved by the resulting organic acid, and enters into circulation. . . .

. . . Red rocks have been coloured in the first instance by solutions of ferrous carbonates and sulphates depositing the insoluble peroxide, and, for lack of reducing agents in sufficient amount, the iron of these beds has not been rendered soluble, and therefore remains disseminated instead of being concentrated. . .].

The author makes no reference to an interesting result which follows from the reactions above described, and which has an important bearing upon the subject of this address. The result referred to is that the deposition of the ferric oxide, like that of the carbonate of magnesia referred to above, is not confined to the strata on the floor of the lake, but is carried down in solution through any pervious strata beneath. We know from geological evidence that this may take place to a depth of fully 600 feet. By this means films of ferric oxide are deposited upon the quartz grains—if little or no carbonaceous matter be present. In this case the quartz grains of the rock below the lake may become coated with ferric oxide to nearly the same extent as happens in the case of the strata in process of formation on the bottom of the lake itself. If, however, carbonaceous matter be present in the strata through which the ferriferous solutions are percolating, then the ferric oxide is wholly or in part

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reduced. In this case the strata, instead of being stained a bright red, are tinted various shades of duller colours, among which browns, purples, and puces are prevalent. Shales containing much diffused carbonaceous matter thus reduce the iron almost entirely, and for this reason almost never exhibit any bright red tint. Their black colour, however, is generally replaced in such cases by dull purple, lilac, or puce. The same is true also of sandstones. Those which contain much carbonaceous matter, or are associated with coal seams or with oil shales, rarely exhibit any very marked staining due to this cause. Thick masses of sandstone, however, in which carbonaceous matter is rare or absent, usually stain a very bright red. As examples, may be mentioned the Upper Red Measures of Fife, of the Glasgow coal-fields, the Whitehaven Sandstone of Cumberland, and many others.

[I have before pointed out that the presence of this distinctive colouring is a sure indication of the former presence of Red Rocks over the spot affected. The first reference to this by myself is in the Explanation of Sheet 98 N.E. of the Geological Survey of England and Wales.]

One further result (of considerable commercial interest in the present connection) is the fact that percolating solutions of ferric oxide tend to *replace* any calcareous matter with which they may come into contact. I have stated my belief[1] that nearly all our British deposits of hæmatite are entirely due to this cause.

The next point that claims our attention is the very marked association of petroleum and the bituminoids[2] with strata formed under conditions of inland drainage. A careful study of the reactions described in Mr Hudleston's paper will make it clear that the precipitation of iron in the form of ferric oxide in inland lakes is one of the results of the absence of any large percentage of organic matter, and especially of matter of vegetable origin. Where much organic matter is present the iron goes back into solution as ferrous carbonate, and is eventually thrown down as ferric hydrate. Where organic matter is rare or absent entirely, and only where that is the case, does the iron go down in the form of ferric oxide. It is precisely under desert conditions that one would naturally expect vegetable matter (and, of course, animal matter too) to be but rarely

[1] Trans. Cumberland and Westmoreland Association, No. viii. (1883), p. 117.

[2] See Goodchild, "Origins of Oil Shales," in this volume; and "The Origin of the Bituminoid Cement of the Caithness Flagstones," *Proc. Roy. Physical Soc.*, vol. xiii. p. 316.

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carried into the schotts, and, even where that is the case, then in but small quantities. We should therefore be prepared to find that where little or no vegetation exists, the strata undergoing deposition would be more or less coloured with the red ferric oxide. Conversely, where we meet with sandstones coloured bright red—especially if these consist largely of rounded grains of sand, and are associated with gypsum, rock salt, and dolomite, and locally contain angular and unweathered fragments of felspar or of limestone—we may correctly infer from these concurrent facts that we are dealing with strata formed under desert conditions. If the underlying sandstones happen to be carbonaceous, and are tinted purples of various hues, and are associated with limestones more or less dolomitised and converted into hæmatite, the inference is considerably strengthened, for the reason given above.

But it must frequently happen that, owing to changing geographical conditions, a region which at one time was under desert conditions may just previously have been, or may soon after become, a region where the conditions may be described as sub-arid, sub-humid, or even humid. Or it may well happen (as in the case of the basin of the Dead Sea, the Salt Lake, and others) that humid conditions prevail and vegetation flourishes in the upper part of the basin, while the lower may be arid in the extreme. Vegetation flourishes in the humid part of the area, and from that part is transported by rivers to the terminal area of the streams, where the water disappears by evaporation. Three chemical changes of importance arise which may perhaps all three be described as changes of a reciprocal nature. (1) Ferric oxide ceases to be precipitated and ferric hydrate goes down in its place. In its turn this brings about a decomposition of the vegetable matter. (2) The sulphate of lime carried into the lake, and there concentrated by evaporation, is decomposed by the vegetable matter, with the concomitant decomposition of precipitates of carbonate of lime. The reciprocal action in this case is that of the action of weak solutions of sulphates, which in the course of time convert the vascular tissues, and even some of the ligneous matter, into one or other of the many hydrocarbon compounds—the bituminoids amongst others. Hence the frequent—or all but universal—association of rock salt, gypsum, dolomite and "abraum salts" with hydrocarbon compounds. It is to this solvent action of solutions of sulphate of lime upon subaqueous masses of ligneous matter that I ascribe the bituminous character of such rocks as the Caithness Flags, the alternations of oil shale and precipitated carbonate of lime which formed the well-known Burdiehouse Limestone, the bitumen of the Dead Sea, the petroleum

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occurring at so many places within the Aralo-Caspian area, and others. Even the pitch in the Pitch Lake of Trinidad appears to me to be due to the uprise of solutions of sulphate of lime through a subterranean carbonaceous deposit.

One more point, and then we may pass on to consider some British deposits which have been formed under desert conditions. In the case of strata formed in inland lakes many other complex chemical reactions must necessarily arise. Amongst these we may refer to the liberation of silica in solution. It has long been known that weak solutions of silica, bathing clean grains of quartz, will tend to be deposited upon the quartz in a crystalline form, giving rise to what is known as Secondary Quartz. The new quartz is not added on to the old anyhow, or at random, but its molecules are so built up as to be oriented in the same direction as were the molecules of the old quartz represented by the sand grain. Therefore, although many millions of years may have elapsed since the time when the quartz of the sand grain was originally formed, and that quartz may have been knocked about, worn, rolled, built up into sandstone, wasted, used up over and over again—yet when suitable conditions again set in (as they appear very commonly to have done during desert conditions), the new quartz tends to restore the old quartz grain to the crystalline form that nature's forces, perhaps millions of years before, had intended it should take.

This preliminary chapter leaves not much to be said in the remainder of the address. I shall now simply point out that the combination of results arising from desert conditions, of which the foregoing is a summary, may be found not only in deposits which are taking place at the present day, but also in deposits which at various, and often widely-separated, periods in the past, have been laid down in Britain. Briefly, these periods may be stated to be three in number—(1) The New Red Period, which is a convenient general name to include the times when the Trias and the Dyas (Lower New Red, or "Permian") were deposited. (2) The Devonian Period, when the various Old Reds of Scotland, &c., were formed. (3) And, lastly, the Torridonian Period. I need only to notice the more salient features of each, and to remind those who read this Address, that I proceed all along on the assumption that in this, as in other geological matters, we interpret the Past by the Present. If the geological evidence shows that we have in Britain strata of the same kind as those which are now only being formed under Desert Conditions, then Desert Conditions pre-

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vailed in Britain at the times when the rocks in question were formed.

Evidence afforded by the New Red Rocks.—While deep water marine conditions obtained on the Continent during the time when the Tyrolian and Panormian (= marine Trias and Dyas) rocks were being formed, inland-continental conditions prevailed in the area now represented by Britain and Western Europe. We have no need to enter into detail in regard to this point; it will suffice to remind the reader that the British strata formed during the period consist largely of bright red sandstones and marls, with which is associated, in the area embracing the north of England and the north of Ireland, a wedge-shaped mass of Magnesian Limestone. With the Marls are also associated both Gypsum and Rock Salt. An inspection of the sandstones shews us that they contain a large percentage of well-rounded grains of quartz, each coated, as a rule, with a thin pellicle of ferric oxide. Plant remains in the red strata are conspicuous by their absence, while the very strongly-marked false-bedding prevalent over large areas at once recalls the diagonal bedding of desert sands.

Breccias, consisting of perfectly-angular and unweathered fragments, occur as old torrential deposits left in connection with the buried wadies, and are therefore found on every platform, from the very lowest to the highest. Throughout the whole of these breccias the angular form and perfectly-unweathered aspect of the rock-fragments, which are also often of large size, is most conspicuous. This is equally the case, whether the breccia consists of a tumultuous assemblage of limestone blocks, as is the case in the Dolomitic "Conglomerate," near Bristol, and, again, in the Brockram of the north of England, or whether the breccia consists of fragments of granite, as it does on the flanks of granite areas in the South of Scotland—for example, near Dumfries.

The uniformity of petrographical characters in these New Red breccias points unmistakably to the occurrence of equally-uniform meteorological conditions over large areas; and shows clearly that these conditions indicate the long continuance of an abnormally-dry atmosphere; a conclusion which no one who studies the facts will venture to call in question.

At the base of the New Red there is some kind of evidence of old wadies; but the inequalities of the old surface are by no means so strongly pronounced as many authors have assumed. In some cases these appear to be due to unequal subsidence.

In Westmoreland (and probably elsewhere in Britain) there is unmistakable evidence of the presence of ice—floating ice in most cases; but in at least one case, that which I have recorded

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in the Proc. Geol. Assoc. for 1889, there is evidence of actual glaciation which is shown by the occurrence of stones traversed by true glacial striæ.

Some important results were deeply impressed upon the rocks, which are, or were formerly, covered by the New Red Rocks. These are the abundant infiltration of ferric oxide into the strata beneath, whereby the sandstones were stained various shades of red—the variety of colouration being apparently connected with the presence, or the absence, of carbonaceous matter in the rocks affected. A further result is the partial, or the entire, replacement of calcareous rocks by hæmatite. Nearly all our deposits of hæmatite—extensive or otherwise—are distinctly traceable to this cause. Yet another result is the dolomitisation of the limestones, due to the infiltration of carbonate of magnesia, which has partially replaced the carbonate of lime, and so converted limestone into dolomites. I have more than once stated before this Society my firm conviction (which has been founded upon many years' field-observations), that the presence of this dull-red staining, the occurrence of deposits, great or small, of hæmatite, and of dolomitised limestones, all concur in demonstrating that the regions where these phenomena occur in rocks older than the New Red have formerly been covered by the New Red Rocks, to which these effects are due.

The widespread diffusion of this red staining amongst the Carboniferous rocks in the basins of the Forth and Clyde, the concurrent occurrence of dolomitised limestones, and the sporadic occurrence of veins of hæmatite in these areas, I therefore regard as some of the vestiges of these old desert conditions which ushered in the Neozoic Era in this part as well as over the greater part of the rest of the kingdom.

Desert Conditions during the Devonian Period.—Much of the evidence already referred to under the New Red applies also to each of the Old Red Sandstones. It need not, therefore, be repeated here. There is the same association of arkoses containing unweathered felspar fragments, the same bright red colour on certain horizons, the same strong false bedding, the same evidence of deposition on a very uneven surface, all of which occur in connection with the New Red. In Scotland especially—thanks to the valuable memoir of Sir Archibald Geikie on the Old Red Sandstone of Western Europe [1]—we can avail ourselves of a vast mass of information bearing upon the

[1] Trans. Roy. Soc. Edin., vol. xxviii. (1878).

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physical geography of the Devonian Period in Scotland. As Sir Archibald has pointed out, the history of these rocks as a whole can be easily comprehended if we can conceive of an unusually-pronounced series of uprises or Geoanticlinals, as they are now often termed, coexistent with their correlative depressions, or Geosynclinals, at no great distance. Denudation from the zone of upheaval supplied the wasted material which afterwards filled up the depressed area adjoining. This process, I conceive, commencing in the period when the English and Welsh Upper Ludlow Rocks were being formed, converted the whilom marine area of the South of Scotland into an area like that of the Nile Valley and the country to the east of it. Under these conditions the Lanarkian (or lowermost "Old Red") Rocks were formed. Possibly the sea may have gained admittance for a short time and permitted of the formation in Scotland of a limestone of Devonian age. But whether that surmise of mine prove correct or not, it is certain that the continued formation of a series of surface undulations, gradually propagated from the south of Scotland northward, permitted of the formation, one after another, of the various Old Reds, and of the denudation which gave rise to the unconformities that separate them, right up to the very top of the Upper Old Red.

There is evidence that, during the time when the Orcadian Old Red was in course of being deposited, normal pluvial conditions obtained for a time. The deposition of ferric oxide in the old area of inland drainage ceased, chiefly in consequence of the large quantities of vegetable matter which were swept into the old lakes. This latter, in its turn, decomposed the solutions of sulphate of lime, and liberated the calcareous matter, which, in a state of diffusion, or aggregated into nodules, now forms so conspicuous an element in the Orcadian Rocks. Furthermore, the sulphate of lime, in its turn, converted the vegetable matter into the bituminoids, which, in a diffused form, permeates—one might almost say saturates—so much of the Caithness Flagstones. I hold, therefore, that the exceptional durability of the Caithness Flagstones, which, of course, is due to the large percentage of bituminous matter they contain, is due to the fact that conditions of inland drainage, one of the phases of desert conditions, prevailed where these occur during the Devonian Period.

Desert Conditions during Torridonian Times.[1]—To my mind one of the most striking and significant illustrations of the

[1] During the past three years, when dealing with the geological history of the Torridonian Rocks, I have taught, in my classes, that these Torridonian Rocks were formed under desert conditions, as stated here. I am not aware that this idea has occurred to any other geologist.

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principle upon which geologists interpret the records of the Past, by the study of the Present, is to be found in the Torridonian areas of the North-West of Scotland. If we review the conditions obtaining in the Sinaitic Peninsular (as was done with the aid of lantern slides when this lecture was delivered), we find going on there to-day almost the exact counterpart of what must have taken place in Pre-Cambrian times in Sutherland and Ross.

In Sinai, and probably also in Scotland, an area of gneissoid rocks was overlaid by a deposit of derivative origin—the Nubian Sandstone in the one case, and some Pre-Torridonian rocks in the other; the area was then elevated in both cases by earth movements into an upland region, while normal meteorological conditions prevailed. During this time rain and rivers carved deep valleys into the massif, in each case cutting down through the overlying derivative rock into the gneissoid rocks beneath. Then changed meteorological conditions set in. Where, before, rain fell and rivers excavated valleys, rain fell only occasionally, or practically never, and only on those occasions when thunderstorms happened to burst over the regions in question. At other times the arid conditions gave rise to great diurnal ranges of temperature. The rocks in consequence were heated soon after mid-day far above the temperature usual in more humid climates, and by early morning, owing to rapid radiation, had cooled down to the opposite extreme. In a rock composed of constituents of diverse mineral character differential expansion takes place, owing to their different coefficients of expansion. The felspars in the rocks, instead of being slowly kaolinised by the action of rain water charged with carbonic acid, gave way under the strain set up by extreme expansion and contraction, due to the rapid changes of temperature. The ferro-magnesian minerals of the gneissoid rocks, having different coefficients of expansion from that of the other constituents, in like manner splintered into fragments so small that they were easily blown away as dust by the wind. Little by little the rocks crumbled down, and of their wasted portions the larger part slid down the valley side as talus, to be eventually distributed and spread out in the bottoms of the wadies by the action of the occasional torrents arising during storms; the remainder, chiefly in the form of dust, was blown far and wide by the winds. Possibly in the case of the old Torridonian rocks these materials from the old gneissic mountains, and their capping of sedimentary rocks, may now and then have been distributed by the agency of lakes; but the agency of water there, as in Sinai and in arid regions elsewhere, may have been limited to the distribution of

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the disintegrated materials by the action of torrents after the heavy rains which occasionally deluge such regions.

In both these cases we have examples of the formation of arkoses, largely made up of the disintegrated materials of the gneiss, with the felspar fragments angular, bright on their cleavage faces, and quite unweathered. The ferro-magnesian constituents in both cases seem to have been shattered to dust, and in that form to have been distributed far and wide by the winds.

In the case of Sinai the disintegration will go on while the present arid conditions prevail, until the wadies are filled with material to the level of the highest point whence their materials can be derived; then their formation must cease and their destruction commence.

In the case of the Torridonian rocks, the old buried mountains, with their wadies levelled up to the brim, were afterwards lowered beneath the waves of the sea, and then planed off to a uniform level, upon which, in later times, when further subsidence had taken place, the Lower Cambrian Rocks were deposited.

The geological importance of the occurrence of desert condition in this, as in other cases, lies in the fact that owing to the felspar fragments being used up in the formation of arkoses before these felspars lost their alkalies, the re-conversion of these arkoses into muscovite schists and muscovite gneisses by dynamic metamorphism affecting them subsequently, was a comparatively simple process. Indeed, owing to these rocks having been formed under desert—instead of pluvial—conditions, the re-conversion of the derivative arkoses into granites or into gneisses will be admitted by most geologists to come well within the range of possibility.

Our British rocks, therefore, present us with records which, when interpreted by the light afforded by modern geographical facts, can only be read as records of desert phases of geographical evolution. As such, they appear to me to possess a high degree of interest, not only on account of the important economic results to which they have given rise, but also because they bring prominently before our eyes the fact that each and all of the various phases of geographical evolution which are taking place upon even the remotest parts of the earth to-day have in the past, at one time or another, found a place in that part of the earth's surface which now forms the British Islands.

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XXIX.—*The Minerals of the Tertiary Eruptive Rocks of Ben More, Mull.* By JAMES CURRIE, Jun., M.A., F.R.S.E.

(Read 21st January 1897.)

SOME fourteen or fifteen years ago, in coming down Ben More in Mull, towards Loch Scridain, I observed in the screes that descend to Allt na Coille Mhoire specimens of scolecite, the crystals of which are longer than have been found, so far as I know, anywhere else in Scotland. These were frequently associated with epidote in radiating brushes and with celadonite. A visit to the locality in September 1896, along with Professor Heddle, enabled me to collect further specimens of all these, and we were also successful in discovering heulandite, stilbite, prehnite, and saponite at the same place. I propose in this paper to describe more particularly the minerals of the southern slopes of the mountain.

The locality referred to above, where the secondary minerals seem to be developed to the greatest extent, is that shoulder of Ben More known as Maol nan Damh, which is composed of beds of varying degrees of hardness, layers of tuff and agglomerate probably occurring between the more durable lava flows. The minerals named occur in druses *in situ*, but they are more easily obtained from the loose blocks among the screes from about 1800 feet above the sea down to 1400 feet.

The occurrence of zeolites and other secondary minerals in the rocks of this mountain has been noticed by former observers;[1] but the references are for the most part somewhat vague, both mineralogically and topographically, and it is often impossible to determine what minerals and what part of the mountain are indicated. Professor Judd, in one of his valuable papers (Q.J.G.S., vol. xxx. 1874, p. 211), refers to "many beautiful varieties of the epidote and garnet groups" of volcanic minerals as being conspicuous in the agglomerates of the Hebrides, and among these the agglomerates of Ben More seem to be included. I have not seen in this locality any mineral referable to the garnet group, nor, indeed, did I observe any "minerals of the same kind as are found in similar positions [*i.e.* ejected blocks] in connection with existing volcanoes." It is unfortunate that the species here referred to are not more exactly indicated. Macculloch, writing nearly eighty years ago, is mineralogically rather more precise,

[1] Geikie, Trans. R.S.E., vol. xxxv. (1888), p. 77; Judd, Q.J.G.S., vol. lxvi. (1890), pp. 346, 368, &c.

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when in discussing "the claystone of Ben More," he remarks[1] that he "observed only two varieties with foreign substances imbedded, the one containing nodules of green earth, the other compact zeolites, apparently solid mesotypes"—no doubt the minerals now more exactly designated celadonite and scolecite. But "Ben More," in its narrowest significance, includes points two miles distant from one another; and if the name be extended, as it may be, to the whole mountain mass of which that lofty peak is the culmination, it covers a district of fully twenty square miles. Scolecite[2] and epidote, entirely similar and in a similar rock, occur near Kilfinichen, on Loch Scridain, two or three miles further to the south-west, and this locality has of course been long known.

The most striking of the minerals found on Maol nan Damh is the *Scolecite*, which occurs in radiating groups of crystals, sometimes nearly 10 cm. long. On two or three of the specimens, where the crystals were freer than usual, we had hopes of observing the termination; but, unfortunately, these were not realised. The scolecite here occasionally fills the druses to the exclusion of all other minerals; but most frequently it is associated with epidote, and more rarely with celadonite or heulandite. Though it loses transparency, it does not weather readily; and rounded masses, that appear to be simply nodules of the rock, often prove, when broken by the hammer, to consist almost entirely of unaltered scolecite.

The *Epidote* varies from pale pistachio green to almost black green; the differences in colour presumably corresponding to variations in the relative amounts of iron and calcium. It is disposed in radiating groups of crystals of the simple form *a c r n*, occasionally doubly terminated, and it has as a rule the habit figured, though sometimes the face *a* is more developed. It often occurs in druses alone, but frequently overlies celadonite, and is in turn overlaid by scolecite or heulandite. The darkest green variety appears to occur on the southern slopes, where the epidote is rarely associated with any mineral but celadonite of a very similar colour. The crystals are about 7 mm. in length, and are finely grouped, forming specimens of much beauty. The resistance which it offers to the agencies of atmospheric decay is very strikingly evident.

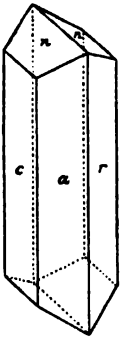

FIG. 1.

[1] "Western Islands," vol. i. p. 576.

[2] The Kilfinichen mineral was analysed by Dr Scott, and yielded SiO_2 46·21; Al_2O_3 27·00; CaO 13·45; H_2O 13·78 = 100·44. It is thus a typical scolecite, entirely free from sodium.

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While the calcite is almost completely removed, the heulandite changed to a milky white, and the scolecite itself rendered opaque or even dissolved away, the epidote remains apparently unaltered, and keeps all its original transparency and lustre.

The *Celadonite* occurs in great abundance, entirely filling most of the smaller druses and the less angular cavities in the rock. The colour is dark green, weathering to a much paler tint; rarely peroxidation has altered it to a rusty brown. It differs somewhat from most of the celadonites of this country. From those of the Old Red and Carboniferous of southern Scotland it is distinguished by its more massive structure, while in colour it is not nearly so bright as are the specimens from Scuir More in Rum. It never exhibits the laminated appearance sometimes seen in the mineral from the latter locality. In view of these differences and of the discrepancies in the existing analyses of celadonite, it would be very desirable to submit to chemical examination specimens of the mineral from Ben More.

A single specimen of what appears to be the rare variety of *Saponite* termed "Prasilite" by Dr Thomson, was found lining a cavity centrally filled with scolecite. The crystalline flakes in this specimen are of a somewhat darker green than most of the celadonite. It may seem unlikely that two minerals, so similar in composition, and both in all probability products of the degradation of the same substance, should occur in the same rock, and even in the same druse; for the outer layer of deposit in this specimen is the ordinary celadonite of the locality. But the close association of two very nearly allied species is not by any means uncommon, and Dr Heddle has already recorded the occurrence in juxtaposition of these very two minerals, and that in the same order of deposition as here. They are found filling the vesicles of the rock near Ferry Port on Craig in Fife, and in this case each of the minerals was identified by actual analysis (Trans. R.S.E., vol. xxix., 1879, pp. 95 and 103). In the Island of Hoy also celadonite and saponite occur in the same rock, though apparently in this case not in the same druses (Heddle, Min. Mag., vol. iii., 1880, p. 248).

The remaining minerals occur much less frequently, and the specimens found were all more or less weathered.

The most frequent is *Heulandite*, invariably milk-white and opaque from incipient decomposition. It occurs in minute crystals with the forms *bstz*, *bstzx* (fig. 2) and more rarely *bstzc*. It is interesting to note the occurrence here of the form *z*, hitherto described—so far as I am aware—only by Greg, from a single locality in the Campsie Hills, Stirlingshire. The

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heulandite of Ben More occasionally lines the druses without associates; more usually, however, the crystals coat tufts of epidote.

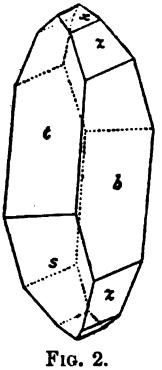

FIG. 2.

Very rarely it occurs in stalactitic arrangements of grouped crystals which present only the faces *t*, *s*, and *b*, sometimes forming an incrustation upon crystals of calcite of large size and of the nail-head form. These have subsequently been entirely removed in solution, so that they are now represented only by the heulandite crust.

A specimen exhibiting this stalactitic arrangement of heulandite, which would appear to be now for the first time noticed, has been deposited in the Museum of Science and Art, Edinburgh.

Stilbite occurs very rarely in opaque much decomposed crystals of the common form (*bcm* of Dana). A single specimen of *Prehnite* was found. This was in white, orbicular, crystalline aggregates, overlaid by hemispheres of radiated scolecite.

The only other macroscopic minerals observed were *Hæmatite*, as a red ochreous incrustation, evidently of comparatively recent origin; and the *calcite* already referred to.

As above stated these minerals were traced to their original position in the rocks of the hill. In the flows which crop out in the screes they form amygdules. Above the brow of the hill, however, no zeolites were observed, and the vesicles contained only celadonite. Near the top of Maol nan Damh—2200 feet above the sea—where the rock is denser and somewhat flaggy, epidote alone occurs. It here lines rents and fissures in the rock, and is of a somewhat paler tint and in smaller crystals than that occurring in the druses of the lower beds.

The minerals yielded by the beds of Maol nan Damh are quite different from those to be obtained in this part of Mull at lower elevations. The rocks around the shores of Loch Scridain, for example, afford analcime in abundance, stilbite, brown saponite, and quartz.[1] One specimen showed analcime of the usual form superimposed on transparent crystals of quartz (*brz*), which is an unusual association. This specimen also has now been deposited in the Edinburgh Museum. Near Torran the quartz occurs as casts of pre-existent rhombs of chabazite. These are now completely dissolved away, but some of the crystals had attained the giant size of 25 mm. breadth.

To the north of the loch, in the basaltic beds, under the cliffs

[1] Zirkel mentions (Skizze der West Küste Schottlands, p. 55), besides analcime, heulandite and natrolite. The former is quite probable, though I have not observed it; the latter is almost certainly scolecite or mesolite.

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of Torosay, gyrolite and pectolite occur (the latter being fully described by Professor Heddle, Trans. Geol. Soc. Glasgow, ix. 241). The more vesicular dolerites here yield stilbite in the usual sheafy aggregates in druses *per se*, and also upon calcite. A single specimen showed stilbite on quartz—an unusual association. There occur further radiated scolecite *per se*; mesolite; analcime on scolecite—alone, or with a still later semi-zeolite superimposed, either gyrolite or more rarely apophyllite in the form *cap*, the latter crystals being 2 cm. across. Other druses contain calcite, reddish saponite, or free silica, both as agate and as crystallised quartz. A single specimen of what may be called milk opal was found. Further along the coast one meets with minerals of a more typically Hebridean facies—faroelite, and analcime on faroelite.

In reviewing the assemblage of minerals found in the rocks of Maol nan Damh, the first fact that naturally strikes us is the peculiarity of the association.

1st. Nowhere else in Scotland does epidote occur in an amygdaloid, either alone or with zeolites, to an extent in any way approaching that exemplified here.

2nd. Nowhere else in Scotland, so far as I know, does Epidote occur with Celadonite.

3rd. Nowhere else in Scotland, again subject to the same qualification, does celadonite occur without the presence of free silica—quartz or chalcedony—as a secondary mineral.

The next point is, that almost all these minerals of Maol nan Damh, and (except the celadonite) absolutely all those that occur in any quantity, contain calcium as an essential constituent.

And, finally, not one of them contains sodium.

These facts taken together would seem to indicate that the rock of Maol nan Damh, by whose decomposition the secondary minerals referred to were formed, was either different in composition from the usually occurring igneous rocks of the country, or has been exposed to different conditions. It must, however, of course, be observed that the two explanations are not mutually exclusive, and that both may be valid.

The rock in question is now in so essentially and radically altered a condition that it is by no means safe to dogmatise as to its original nature; but it may at least be regarded as reasonably certain, from the evidence of the decomposition products, that among the original constituents were—*firstly*, either anorthite or a labradorite rich in calcium, and thus approximating to anorthite in composition; *secondly*, some species of pyroxene, either rhombic or monoclinic; and *thirdly*, magnetite or olivine.

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The large amount of celadonite may perhaps further indicate the former presence of biotite.

I can hardly believe that the slight divergence from the type of a normal dolerite which is all that is indicated by this composition is sufficient to account for the distinctly anomalous assemblage of secondary minerals here presented. If not, it would appear necessary to call in the aid of some agency differing in kind or in degree from those which have operated in general on the igneous rocks of Scotland; and it is difficult to avoid the conclusion that the processes of decomposition have been here facilitated and augmented by pneumatolytic action of a nature unusually vehement or unusually prolonged.

Scolecite when present in any rock is generally one of the earliest formed zeolites, and its very marked predominance here would seem, therefore, to point to a long continued period of relatively high temperature, indicating probably the near neighbourhood of a very considerable mass of molten rock. In this way when the vesicular rock had cooled sufficiently to permit of the formation of other zeolites, the cavities were already in most cases filled with scolecite.

There is evidence that the order of events was, in outline, as follows:—There was to begin with a pneumatolytic stage in which first the pyroxene was attacked, yielding celadonite, and then the feldspar, affording most of the epidote. Continued cooling allowed the condensation of the vapours, and a hydrothermal stage followed in which the heated aqueous solutions acting on the feldspar deposited scolecite, and afterwards, at a still lower temperature, heulandite and stilbite. To meteoric water, acting at the ordinary temperature, we can hardly attribute more than the formation of the hæmatite and the removal of the calcite.

In the same way we may, independently of probable lithological distinctions, explain some of the differences between the zeolites of the rocks at Torosay and those of Maol nan Damh. Further removed as the former were from the source of heat that maintained the Ben More rocks at a high temperature, there was little or no pneumatolytic action, the cooling was more rapid, and the production of scolecite was less abundant. Thus when the temperature had fallen to a relatively low point there was still a sufficient supply of lime and silica to form minerals like apophyllite and gyrolite, and still sufficient room in the vesicles to afford space for their deposition and growth.

These are only some of the problems presented at this interesting locality, which will well repay careful investigation. In concluding this brief contribution, I may perhaps be

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permitted to express the opinion that in such investigations it might be well if petrographers would not confine themselves exclusively to the microscope, but would pay more attention than they often do to those decomposition products which are visible to the naked eye. In few localities can more instructive examples of secondary igneous minerals be studied than those which are presented so lavishly and in such varied and beautiful forms in the eruptive rocks of the Hebrides.

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XXX.— *On the Occurrence of Sillimanite Gneisses in Central Anglesey.* By EDWARD GREENLY.

(Read 21st January 1897.)

(Abstracted from the *Geological Magazine*, Nov. 1896.)

THE author records the occurrence of gneisses and schists containing Sillimanite among the rocks associated with the granites of Central Anglesey. The Sillimanite occurs partly as fine needles in quartz ("Faserkiesel"), partly as matted bundles in brown mica ("shimmer-aggregates"). Sections near the Holyhead Road show that the granite penetrates the schists in a complicated series of sills, which, though lying for the most part between parallel folia, demonstrate their intrusive character by frequent transgressive junction and by containing many included fragments of the schists. No chilled edges have been observed. The whole series of phenomena appears to be of the same nature as those observed by Mr J. Horne and the author in Eastern Sutherland (Q.J.G.S., 1896, p. 633).

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XXXI.—*Note on Cambrian Hyolithes Sandstones from Nuneaton.*

By Professor CHARLES LAPWORTH, LL.D., F.R.S., F.G.S.
Communicated by the President.

(Read 18th February 1897.)

THE fossiliferous rocks belonging to the now famous *Olenellus* Zone or basement Cambrian series were practically unrecognised by the majority of geologists ten years ago. They are now, however, known to have an almost universal extension on both continents north of the Equator, from India to Lapland in the Old World, and from Virginia to British Columbia in the New.

Fossiliferous beds belonging to this Lower Cambrian zone have been recently found to occur in their proper place among the well-known Cambrian quartzites of Nuneaton and Atherstone, and the fossils, which are many of them well-preserved, include *Hyolithes, Coleoloides, Kutorgina, Scenella,* etc., of the same type as those which occur in the lowest Cambrian rocks of Scandinavia and Newfoundland.

The first indications of fossils in this Midland zone were detected by Dr Stacy Wilson in July 1895, and the actual fossil-bearing beds were subsequently followed and worked out in the field by myself.

It is exceedingly interesting to find the same general succession of Cambrian rocks in the English Midlands as in all those regions in Britain and abroad, where the well-known Cambrian quartzite band forms the lowest bed of the Cambrian system. The fossil-bearing layers in the Midlands come in, as usual, between two sets of arenaceous strata, namely between a lower sandy series—the well-known Nuneaton or Lickey quartzite—and a higher and thinner arenaceous series, which appears to be the local equivalent of the well-known Salterella Grits and Hollybush Sandstone of other districts.

It thus becomes more clearly evident with each new discovery, that on this side of the Atlantic a fairly uniform set of geographical and biological conditions prevailed in Cambrian times over the whole of that European region which ranges through Central Scandinavia, North-West Scotland, and Central Britain. In the same way, as shewn by the recent discoveries of Walcott and other American geologists, a corresponding set of practically similar conditions prevailed over Eastern America from Newfoundland South to Central Virginia.

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While, however, trilobites are the most generally distributed and best known fossils in the Lower Cambrian zones of the Continents of Europe and America, we find the collections from our Midland Zone made up almost wholly of the conical shells known as *Hyolithes* and the like, which are comparatively rare fossils in the extra British Cambrian deposits that contain trilobites. The form of *Hyolithes*, etc., found in the Midlands are all of the same type as those of Cambrian deposits elsewhere. The exact horizon of the Hyolithes Zone of the Midlands cannot yet be regarded as absolutely fixed. That it is Lower Cambrian is regarded as more than probable. That it answers to any special part of the Olenellus Zone has yet to be determined.

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XXXII.—*Note on the Occurrence of Limestone Nodules containing Cementstone Fossils in Glacial Deposits near Moffat.* By Mr JOHN T. JOHNSTONE.

(Read 18th February 1897.)

IN the spring of 1877, when excavating for sand at Ellerslie Villa, old Edinburgh Road, then in course of erection, I observed certain small nodules of a dark brown colour and of a semi-pasty consistence in the deposit pierced during the excavation.

On carefully extracting some of these nodules I observed that casts of fossils were quite apparent in some of them. These, after being dried, were seen by Mr Peach and Mr Macconachie, of the Geological Survey of Scotland, who pronounced them to be decomposed limestone.

A doubt having since arisen as to the exact nature of the deposit in which these nodules were found, it was deemed advisable to make fresh excavations last autumn to set the matter at rest. The point in dispute was whether it might be a true glacial deposit or merely the permian breccia decomposing *in situ*, which is so abundant in the locality. (See Essay, Geology of Dumfriesshire, in Mr Scott Elliot's flora of that country, p. xxxv.)

In this neighbourhood the permian breccias and sandstones are the prevailing rocks underlying the till on the east side of the valley, and sections are seen in all the tributaries of the Annan on that side; these beds are also exposed on several places on the adjoining hill sides. On the west side of the valley near Moffat no exposures of this formation have been noted except one patch in a small burn nearly opposite the centre of the town.

This formation extends southwards along the east side of the valley for a distance of seven miles from Moffat. In the Lockerbie basin, which is disconnected from that of Moffat, it reaches a greater development.

This breccia has not the appearance of having been much disturbed. In some of the sections it is lying nearly horizontal, in others at a very small angle, and in the cutting at the back of the Hydropathic establishment the inclination is about 20 degrees. The pebbles embedded in the breccia are composed mainly of Silurian grits and greywackes, like those occurring

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so abundantly in the neighbourhood of Moffat. Fragments of black shale are also to be seen in it. The pebbles are of various sizes, and are generally sub-angular. The nearest visible exposure of this breccia is about 250 yards distant from the locality yielding the fossiliferous pebbles.

No notes were made regarding the original excavations; but, writing from memory, I might state that the excavations would be about 8 ft. long, 4 ft. wide, and 3 ft. deep; but the original surface had been previously excavated to a depth of 3 feet. The nodules were found lying near the bottom, and would be in the proportion of three to the superficial yard.

The new sections were made on the 26th and 27th November 1896, and were taken at different places, but in immediate proximity to the original place.

No. 1 cutting was 5 ft. long, 7 ft. deep, and 2 ft. wide. This cutting was made in a field which had its original surface undisturbed, and hence the extra depth of cutting. After the surface soil was removed the whole cutting was made through a sandy till, striated stones being found from the surface down to the very bottom of cutting; these striated stones were lying with their long axis parallel to the valley, with a dip downwards of 10 degrees. Small portions of the material excavated could be recognised as being fragments of the breccia, but no limestone nodules were found in this cutting.

No. 2 cutting was 3 ft. long, 2 ft. 6 in. deep, and 2 ft. 6 in. wide. This cutting had the advantage of having been previously excavated and removed to a depth of 3 feet from the level of its original surface, and hence the small depth of the excavation as compared with No. 1.

The stones in this cutting were all striated as in No. 1 section, the description of which will apply equally to No. 2. In the latter cutting we observed two nodules—one in the very bottom and one in the side. One of the striated stones measured 10 inches in length and 5 inches across. The nodules themselves varied in size, from a hen's egg to blocks about 5 inches by 3 inches. None of the cuttings was deep enough to reach the rocks, but the evidence of the striated stones may be held as proving that the material in which they occur is a glacial deposit, although the material of which it is composed is principally derived from the destruction of the permian sandstones and breccias.

I have examined the breccias where exposures of it are seen, notably at the site of the Hydropathic establishment, but have never detected any limestone nodules in it.

Since the first discovery of these nodules I have examined nearly all the excavations that have been made for building

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purposes or otherwise in the immediate neighbourhood, and have found these nodules in nearly every one of them, from Ellerslie Villa down to where the till on this section of the Annan vale tails out at the Moffat academy, a distance of nearly half a mile in length by about 100 yards wide.

In excavations observed south from the academy no nodules have been observed, although the material excavated has been a red sandy till likewise.

Mr Peach informs me that the fossils occurring in these nodules are *Camerophoria crumena* and *Naticopsis plicistria*, forms which are characteristic of the lower marine bands of the cementstone series of the south of Scotland.

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XXXIII.—*Remarks upon a recent Boring for Water at North Berwick.* By Mr GOODCHILD, H.M. Geological Survey, F.G.S., Curator of the Collections of Scottish Geology and Mineralogy, Edinburgh Museum of Science and Art.

(Read 18th February 1897.)

NOTWITHSTANDING the fact that the rocks in and around North Berwick are exposed at the surface in an extensive series of fine natural sections, and also that the district has long been a favourite resort of geologists, there yet remains considerable uncertainty with regard to the position in the Lower Carboniferous Rocks of many of the minor subdivisions which are so admirably displayed in the coast section there. Practically the only point in the whole coast line, from Aberlady to Dunbar, whose geological position can be fixed with any degree of certainty, is represented by the limestones seen at the first-named locality. These certainly pertain to the lower part of the Yoredale Rocks, and are not, as many people still continue to believe, equivalent in time to any part of the Mountain Limestone, properly so called, of the North of England. In the neighbourhood of Edinburgh and in Fife these Yoredale Limestones overlie the Oil Shale Series, which has, in both localities, a thickness of several thousands of feet, and which, it may be added, is represented in Northumberland by the Scremerston Coal Measures. Beneath these comes the great series of estuarine and marine sandstones and shales, which are known in Northumberland as the Fell Sandstones, and around Edinburgh as the Granton Sandstone Series. These have an aggregate thickness of at least 2000 feet. In turn these overlie the Cement Stone Series, or the Ballagan Beds of the West of Scotland. These, again, are developed to a considerable thickness in Northumberland, on the Berwickshire coast, and around Edinburgh. Below the Cement Stones or Ballagan Beds lies a series of beds whose thickness varies much in different areas. The strata referred to correspond to the Lower Limestone Shale of English geologists. They are represented near Edinburgh by the Craigmillar Sandstones and the sedimentary rocks seen at Salisbury Crags. Below these comes the Upper Old Red Sandstone, which also is extremely variable in thickness, and which, on the south of Edinburgh and east of Dunbar, must be fully 2000 feet in thickness.

It is the lower members of the Carboniferous Rocks just noticed which are most variable alike in their thickness and in their petrographical characters. But from the Cement Stone

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Series upwards this variability is by no means so marked a feature as it appears often to have been assumed was the case.

In those cases where volcanic rocks have been deposited amongst, or in the place of, the rocks of normal sedimentary origin, there does not seem to be any valid reason for believing that the total thickness of rock of both kinds between one known geological horizon of sedimentary rocks and any other known horizon on either a higher or a lower level, should be more variable where volcanic rocks are present than where they are absent. In any case, where such difference has been proved to exist, experience has shown us that the aggregate thickness of rock is above, rather than below, that normal to the district in question.

Applying these principles to the case of the rocks specially under notice would lead one to expect at North Berwick to meet with the normal thickness of rocks between the lowest of the Yoredale Limestones of Aberlady, Dunbar, and the Berwickshire coast, and the equivalents of the Ballagan Beds or the Cement Stone Series.

There is considerable difficulty in deciding this matter on the ground, for the rocks around North Berwick itself are so much disturbed and faulted that only a rough approximation to their thickness can be arrived at from a study of the facts actually seen at the surface. It is true that there is seen on the shore, associated with the volcanic rocks, just west of the town, and also at one or two places inland, a band of limestone whose petrographical characters forcibly remind one of the well-known limestone of Burdiehouse. But in making use of this evidence, it has to be remembered that bands of limestone of almost identical character occur in connection with Scottish Lower Carboniferous volcanic rocks on many different geological horizons. There are at least three such bands on different platforms amongst the older volcanic rocks of Arthur Seat, and rocks of identical character occur on a much higher geological horizon in association with the volcanic rocks of the Bathgate Hills. There are many reasons for regarding these finely-banded and cherty limestones as old geyserites, and as therefore from their very nature necessarily of very local distribution. Mere similarity of petrographical character is no guide whatever to the geological position of the strata among which rocks of this description happen to occur.

The only really safe guide in determining the sequence, the thickness, and the geological horizon of any given set of rocks, in a case like that specially under notice, is that afforded by borings, such as those made for water supply. Thanks to the spirited enterprise of Mr John Macintyre, of North Berwick, one such borehole has lately been sunk there. Mr Macintyre

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desired to obtain a supply of water of a special quality suitable for the manufacture of aerated waters. To this end he sank a well near his house, in the middle of the town, to a depth of about 614 feet. The following record of the bore is from the journal of Mr Robert Henderson, the well sinker:—

JOURNAL OF A BOREHOLE AT MR MACINTYRE'S, NORTH BERWICK, 1897.

		Ft.	In.
1.	Superficial deposits	12	0
2.	Reddish tuffs (some water at 154 feet)	210	0
3.	"Blue volcanic matter"	19	2
4.	"Grey volcanic matter"	15	0
5.	"Red and green volcanic matter"	1	8
6.	"Grey volcanic matter"	6	0
7.	"Red and green volcanic matter"	15	7
8.	"Red and green strains and ribs"	68	4
9.	"Red and green strains, hard"	2	11
10.	"Limy band, hard"	0	11
11.	"Red and green strains"	9	0
12.	"Red and green volcanic matter"	13	9
13.	"Blue and green volcanic matter"	31	8
14.	"Fireclay blaes and hard limy bands"	23	5¾
15.	"Dark blaes with limestone bands" [This was at a depth of 413 ft. 7¾ in., reached in April 1896.]	3	1
16.	"Clay"	0	10
17.	"Blue blaes with white streaks"	3	11
18.	"Fireclay"	1	4
19.	"Dark blaes with limestone bands"	19	2
20.	"Blue blaes"	14	0
21.	"Purple and green streaked fakes and blaes"	41	0
22.	"Red and blue ashey material"	18	0
23.	"Dark blaes"	2	10
24.	"Limestone, hard"	0	8
25.	"Dark blaes"	1	4
26.	"Red and blue blaes and ash"	10	0
27.	"Blue shaley blaes"	3	0
28.	"Red and blue blaes"	11	0
29.	"Blue shaley blaes"	3	0
30.	"Bluish grey ashey material"	14	6
31.	"Dark and grey sandstone with plies of ash"	30	0
32.	"Red fakey blaes"	3	0
33.	"Fireclay"	0	6
34.	"Grey sandstone"	19	0
	Total depth, 31st Dec. 1896	613	9¾

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In the above record the journal of the boring has been followed throughout, except in the wording of Nos. 1 and 2.

As regards the position of these beds in the general series, it may be useful to make a few remarks here. The prevalent dip of the rocks around the site of the borehole is mainly westerly, varying to north-westerly in places. Higher beds therefore, on the whole, come on towards the west. The rocks are chiefly of volcanic origin. The highest part of the series consists of trachytic and andesitic lavas, whose upper beds pass close beneath the Yoredale Limestones of Aberlady Bay. The base of these lavas is seen on the North Berwick shore, at the western end of the West Links, where the lavas are seen to overlie a series of sandstones and beds of tuff. These include the band of geyserite already referred to. The beds roll about a great deal, and for some distance to the north-west of the town have a northerly, instead of a north-westerly, dip. This, combined with the effects of a fault, brings down the base of the lavas again to the east of the place above mentioned, where their hardness enables them to form the small promontory known as the Kirkness. Here three trachytic, or phonolitic, lavas are seen overlying tuffs and sandstones, including one thin bed of lava. It is these same tuffs which are displayed on the foreshore to the east of Kirkness, and which show so well the very remarkable poikilitic mottling, for which this part of the coast has so long been celebrated. It is evidently in these beds of tuff (C) that the well section has been started. As far as the imperfect nature of the evidence will enable us to judge, the well section commences at about from one hundred to one hundred and fifty feet below the base of the lavas. Assuming that this estimate is not far from the truth, the broader features of the succession at North Berwick will read much as follows :—

		Ft.	In.
A	Lower series of trachyte and andesite lavas (thickness not estimated)	...	
B	Alternations of sandstones and tuffs with bands of geyserite (seen on the foreshore N. of the West Links) [about]	50	0
C	Spotted and poikilitic tuffs [about] . . .	500	0
D	Sandstones and shales with thin geyserite (seen near Horsecrook)	110	0
E	Tuffs alternating with thin sandstones . .	18	0
F	Alternations of shales and flags, with one or more thin bands of geyserite (also seen at Rhodes Quarry)	50	0
G	Tuff alternating with thin sandy bands . .	14	6
H	Grey sandstone with shaly bands . . .	52	0

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It is difficult to estimate, even approximately, the depth below the Hurlet (Yoredale) Limestones of Aberlady Bay, at which these sandstones (H) occur. It may be about two thousand feet, but it cannot, unless the rocks are much faulted, be very much more than that. If we assume that the thickness of the beds between the top of the Ballagan Beds and the Hurlet Limestones is not subject to any very considerable attenuation here, the sandstones proved at the bottom of the borehole might well belong to the lower sandstones of the Oil Shale group, with which, by the way, they closely agree in general character. There cannot be much doubt that, whatever may be their equivalents elsewhere, these lowest sandstones of the borehole are part of the underground extension of the sandstones which form the crags just to the west of Canty Bay. I understand that my friend Mr Peach is inclined to refer these Canty Bay sandstones to a much lower horizon in the Lower Carboniferous rocks. However that may be, these Canty Bay sandstones are exposed over a fairly large area, and as they are very pervious it was naturally expected that water would drain downwards further into the strata below North Berwick, and that therefore water of a quality suitable for Mr Macintyre's purpose would be found when that stratum was reached in the well boring. Geologists will learn with much regret and some surprise that such did not prove to be the case. Mr Macintyre's spirited enterprise has so far resulted in not meeting with anything like the quantity of water required, and the boring has had to be abandoned. Why so little water was met with is difficult to answer. It is possible that communication between the sandstones of Canty Bay and those below North Berwick may be interrupted by a fault, of whose existence there is some kind of evidence at the west end of Rugged Knowes, and clear proof on the south-west side of Kirkness. But I think it probable that the rocks seen at Rugged Knowes and the landward side of the Leithies may form part of a neck, and that it is this which has cut off the water which otherwise would naturally drain to lower levels in the direction of North Berwick, and forms a water-bearing stratum there.

I should add that I am indebted to Mr A. R. Mackay for part of my information about this well, and also for specimens of the cores from the lower depths. Some of these cores are now located amongst the Scottish Rocks in the Edinburgh Museum of Science and Art, where they may easily be inspected by those interested in the matter.

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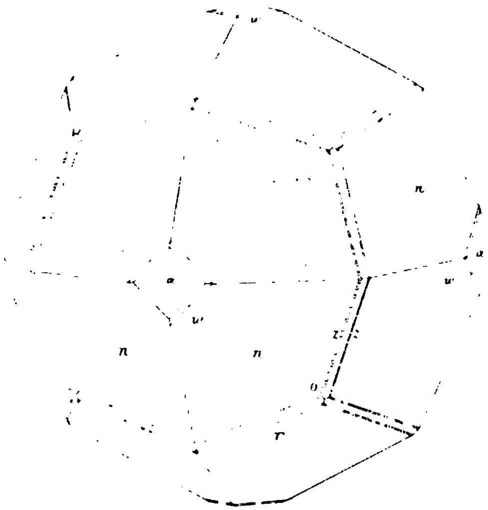

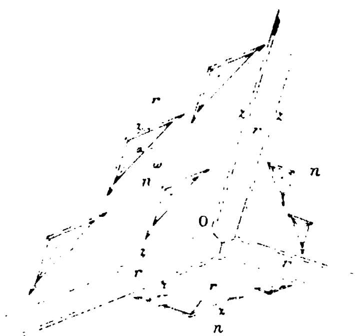

Angle O

M. F. Heddle del.

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ANALCIME

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XXXIV.—*On Analcime with New Forms.* By Professor M. F. Heddle, F.R.S.E. (Plate XII.)

(Read 18th March 1897.)

Boylestone Quarry, near Barrhead in Renfrewshire, is, or rather was, for it is temporarily at least exhausted, a storehouse of zeolites.

It did not yield so many species as did the great quarry at Bowling; but such specimens as Boylestone yielded were obtained continuously or regularly—those at Bowling being got for the most part only when the two great prehnite veins were being removed.

In Boylestone, as in Bowling, prehnite was very much the most common mineral; in the former analcime stood next in frequency of occurrence, and was much more frequent there than it was at Bowling.

The appearance, though not the association, of the mineral is different in the two quarries. The groups formerly obtained at Bowling were cream-coloured, opaque, and dull on the surface; the usual associate was thomsonite, in groups of long radiating crystals. The crystals from Boylestone are white — purer than what Ruskin calls "paper-white." The usual associate is still thomsonite—here however it is in bladed crystals, of the form which I have already described and delineated.[1] The specimens formerly obtainable of this Boylestone white analcime were the most showy to be got from any British locality, being superior to the Irish specimens, and even to the pale blue variety from Talisker in Skye.

In addition to these opaque white specimens, however, Boylestone supplied us, though very much more rarely, with analcime of an entirely different appearance. Upon the surface of mammillations of pale-green prehnite there were occasionally sprinkled isolated crystals of perfectly colourless and perfectly pellucid analcime. It is certain of these only which carry the new faces.

The crystals of the specimen on which I first observed them are only about the sixteenth of an inch in size, and they do not, like the large and opaque crystals, in any way evidence a composite or tesselated structure.

The predominant form is the deltohedron n (211), but the crystals

[1] Min. Mag., vol. vii. p. 136.

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carry in addition the faces of the cube *a* (100)—always irregularly developed; an adjacent very flat deltohedron *w* (*m* 11); the faces of the trigonal trisoctohedron *r* (332)—truncating those edges of the leucite faces which converge upon its octohedral angles; and an exceedingly narrow face lying between *r* and *n*. This last form is a hexoctohedron, a type which has not hitherto been observed in analcime. The other edges of *n* seem also in some of the crystals to be bevelled. The two hexoctohedra are represented by such exceedingly narrow, although brilliant, faces, that it has been impossible to measure them accurately with any goniometer at present in my possession; they seem, however, to be *z* (543), and *t* (421) respectively.

The surfaces of the faces *n* are profusely pitted by a system of somewhat symmetrically arranged depressions of triangular form. These are exceedingly minute; but reflected light and high magnification show that they are definitely bounded by the faces *r* and *z*, which form the sides of a very obtuse triangle, and by the faces *a w*, which form its base.

A highly magnified plan of their arrangement is shown in the corner figure.

It has been stated above that the faces *a* are always irregularly developed; they are generally, through the dominance of two opposite faces, reduced to mere lines. Inasmuch as everything points to the crystal of analcime being composite—one of the *tesselites*—I had hopes that the direction of these lines—whether they lay alternately at right-angles to each other or not, or in any definite arrangement—might indicate the system to which the primary crystal belonged.

In most of the crystals opposite sets of the leucite 3×8 faces truncate most deeply. This would seem to indicate a tetrahedral tendency, and crystallographic simplicity; and, as already stated, they do not exhibit the usual evidences of composite structure.

As is well known, the deltohedron *n* is the characteristic form of analcime, and generally occurs alone. The only other form which is at all frequent is the cube. Out of over fifty different localities for this mineral in Scotland there are only eight in which any form but *n* occurs, and in all these (except Boylestone) the sole additional form is the cube. These eight localities are—Sandsgeo in Walls; Gapol (Kinneff); Glen Farg; Kelly Law, near Elie; Bowling; Kilpatrick; Hartfield, in Renfrewshire (prehnite pseudo after analcime); and, lastly, Boylestone.

The other forms which occur in analcime are excessively rare, some of them being limited to a single locality. The only localities given by Hintze are—

Friedensdorf, in Nassau, (211) (110) (100) (210) (332).

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Vesuvius, (211) (100) (110).
Cyclopean Islands, (211) (100) (*m* 11).
Phillip Island, Victoria, (211) (111).
Kerguelen Island, (211) (332).

It is evident that the Boylestone specimens, which show the combinations (211) (100) (332) (543) (*m* 11)...(421), *narzw*...*t*, are the most complicated yet observed of this usually excessively simple mineral; and it is certainly remarkable that while nowhere else in Scotland are crystals found showing more than two forms, those at Boylestone exhibit no less than six, of which two have so far never been found elsewhere.

It is worth noticing also, that although analcime is one of the commonest zeolites of the Tertiary Traps of the Hebrides, the form there is invariably the simple deltohedron. All the Scottish examples mentioned above, where the cubic faces are developed, are from igneous rocks of palæozoic age.

A similar tendency to great (apparent) simplicity is observable in the crystals produced artificially, which are always either deltohedrons, or combinations of that form with the cube.

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XXXV.—*On the Occurrence of Gasteropods (Platyostomella Scotoburdigulensis) in a Lepidodendron from Craigleith Quarry, Edinburgh.* By CAMPBELL BROWN, M.A. (Plate XIII.)

(Read 18th March 1897.)

IN connection with the building operations at Leith docks, a new quarry which lies at the north-east corner of the old one has been opened up at Craigleith. A fault of no great size with downthrow to the north, marks the division line between the old and the new quarries, and the beds on the downthrow side are considerably turned up. About 85 feet of strata have already been removed, consisting for the most part of a yellow sandstone much discoloured by iron oxide. A band of shale and thinly bedded sandstone associated with it have also been cut through, and the white micaceous sandstone or liver-rock for which Craigleith has so long been famous, has now been reached.

The rocks exposed at this quarry belong to the lowest group of the Calciferous Sandstone series, and form the top of the Granton Sandstones. Overlying these, a small outcrop of the base of the Wardie Shales may also be seen. The beds of sandstone are arranged in lenticular fashion, and thin out in both directions, dovetailing with each other. Many of the beds are extremely rich in plant remains; so much so, that between the laminæ thin layers of a black coaly substance appear, representing what must have been a vast quantity of drifted vegetable matter. Evidence of shallow water conditions is not wanting. Sun-cracks, worm-tracks, rain-pits, ripple-marks, and footprints of labyrinthodonts have all been found in this quarry, which make it safe to assume we are dealing with an estuarine deposit.

During a recent visit to the new quarry, my attention was attracted to a block of sandstone quarried from the beds underlying the shaley beds above referred to. The block shewed current bedding in a fine scale and contained several Lepidodendron remains. The largest of these was a portion of an old trunk, measuring about 14 inches across and over 3 feet in length. How long it may have been originally it is impossible to say, as the contiguous block must have contained the remainder, and had already been removed. The tree was somewhat squashed or flattened, as is usual for lepidodendroids, and

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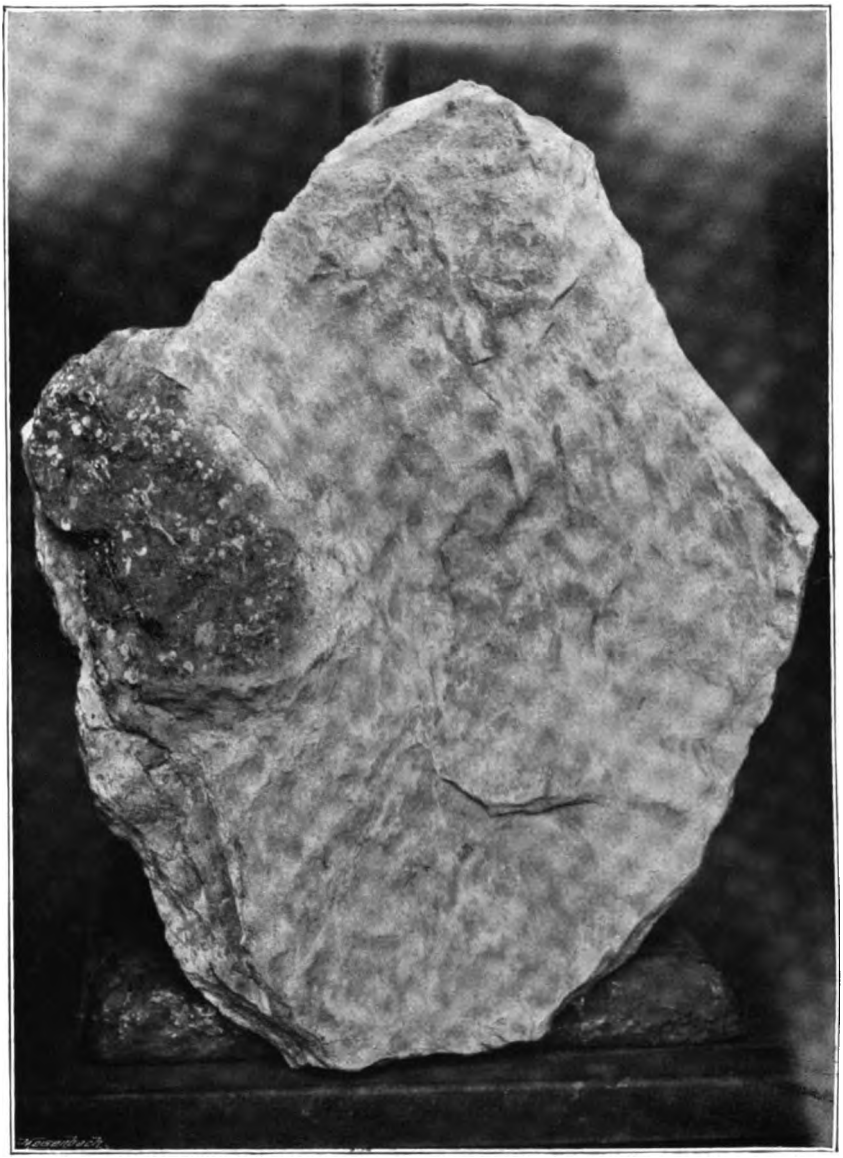

PORTION OF A LEPIDODENDRON CONTAINING GASTEROPODS.

(Platyostomella Scotoburdigalensis).

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retained some remnants of its original bark in the form of a thin pellicle of coal here and there. It lay in a horizontal position, or rather parallel to the general direction of bedding of the sandstone. The internal structure of the tree is represented in Fig. 1 by a cross-section. In the interior towards the right in the lower portion (shaded black in the figure), a thick layer of a deep brown coloured deposit was seen, the rest of the interior being filled up with finely laminated sandstone. In removing the fossil it split along a plane parallel to its length, and exposed to view several nests or patches of the brown-coloured deposit above referred to. These on closer examination, I found to contain the tiny little shells of a gasteropod. Fig. 2 shews the distribution and position of the nests in the the interior of the tree, as it lay in situ. The nests were four in number, three of which were roundish or elliptical in shape. The fourth or largest was broken across, as is indicated in the figure, and must have been of irregular outline. The maximum thickness of this larger patch was fully an inch; while the others varied from $\frac{3}{4}$ to $\frac{1}{2}$ an inch as maximum. These nests were quite isolated from each other and thinned out slightly towards their edges, but stood boldly through the laminæ of sand surrounding them, giving them at first sight a concretion-like appearance. In every case they contained the shells of the gasteropod. Not only so, but the shells were entirely confined to them. I broke up the greater part of the Lepidodendron, but was unable to find any traces of them in the sand immediately above or surrounding the nests in the interior of the tree. The bases of the brown-coloured nests to which the shells are confined all lay in the same plane, clearly shewing that the gasteropods took up their position in the interior of the Lepidodendron at one and the same time; and in general aspect and position these nests were precisely similar. The

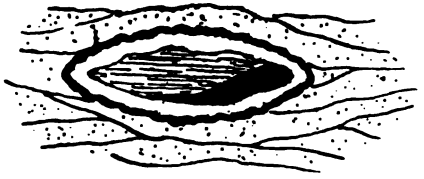

FIG. 1.

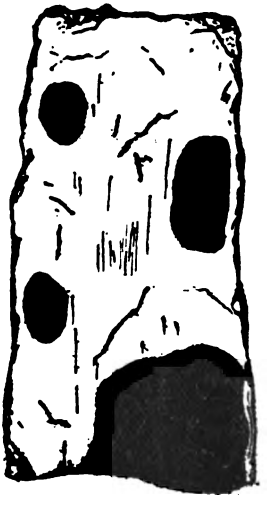

FIG. 2.

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laminæ of sand with which the interior of the tree is filled are very fine and regular, bespeaking a somewhat slow and gentle deposition, and their relationship to the nests is extremely significant. The lines of lamination, as the plate which accompanies this paper shews, go up to but do not penetrate the deposit containing the gasteropods, and are continued again on the other side of it. When the summit or point of maximum thickness is reached, the laminæ are seen to swing in a continuous curve over the top of it. We are thus furnished with unmistakable evidence that the shells were in the interior before the sand was laid around and over them.

Another significant fact is, that the shells do not show the faintest attempt at orderly arrangement. They seem to lie in a confused jumbled heap in the matrix, and in some cases present a packed appearance as if they had been hustled into the tree during turbulent conditions. Had they been borne in by the same water which deposited the sand, they would naturally have arranged themselves in regular parallel rows, spreading out in thin continuous bands. Instead of that, we have them confined to isolated concretion-like nests, without even a stray individual here and there in the sand around.

In order to remove the shells, I washed the deposit from two of the nests, and was thus able to secure about 400 tolerably perfect specimens free of the matrix. The shells being so small and delicate, I experienced some difficulty in obtaining any absolutely entire. Associated with them I found a number of small pebbles of quartz. Most of these were water-worn, but in at least two cases had sharp angular outlines, and had suffered no apparent detrition. There were also many little flakes of carbonaceous matter, for the most part indeterminable. The finer residue I examined under the microscope, and found to consist of various materials. Numerous angular fragments of shells, little broken flakes of carbonaceous matter, imperfectly rounded grains of quartz coated with limonite, muscovite and biotite, some tourmaline, zircon, one garnet, and a good deal of iron pyrites. The grains of quartz alone were at all well rounded. The other minerals were distinctly angular, and showed sharp jagged edges where fractured, and in some cases, traces of crystalline outline. For comparison I also submitted the sand from the immediate proximity to the nests to microscopic examination. This was found to consist almost exclusively of quartz grains with muscovite, the quartz in this case being as a rule more rounded than in the previous case. Not a trace of shell *débris* was visible. The microscopic difference between the white sand and the calcareous nests containing the gastropods would thus seem to be as strongly marked as the macroscopic.

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When moistened with water and freed of the shells, the matrix forms a plastic adhesive mud clinging with great readiness to the side of the containing vessel. If allowed to dry, it becomes a hard solid mass, which when broken up into a state of fine division, has a soft earthy feel. In washing the deposit I looked very carefully for the presence of other organic remains along with the shells. At first I was at a loss to account for the presence of several imprints or upper casts of what must have been minute bodies with a grooved and pitted surface. At last I found several very small portions of plant remains, which apparently had been calcified. On making a drawing of these with the aid of a lens, the resemblance to the bark of the lepidodendron was at once manifest. To see if the markings produced by them corresponded to the imprints I had already found, I made an impression with them on soft wax, and found they were identical. An exceedingly small conical body was also found with a blunt apex and grooved exterior. It was not more than $\frac{1}{8}$ of an inch in length, and its base showed an uneven outline, proving that it was the fractured terminal portion of something, but of what there was not sufficient accurately to determine. Mr Peach, who kindly examined it for me, suggested it might be the base of a Zaphrentis coral; but on making a microscopic section of it, it showed no internal structure whatever.

The shells of the gastropod are, on the whole, well preserved and are white in colour, and vary slightly in size. The larger ones have the appearance of being fully developed, the smaller ones probably not yet having reached maturity. They are composed of $3\frac{1}{2}$ to 4 whorls, the body whorl being much larger than the rest of the shell. This is the little gastropod that Mr Etheridge referred at first to the genus Littorina;[1] but on securing better specimens, had reason subsequently to alter its name to Platyostomella Scotoburdigalensis.[2] Our previous acquaintance with this beautiful little shell is entirely due to the research of Mr Bennie and Mr Henderson, members of this Society. Indistinct rings of growth may be seen on several of the shells from the Lepidodendron, but no colour bands, unlike those figured by Mr Etheridge. On comparing them with those figured, a much stronger general resemblance to the Naticopsis will at once be seen than any of those from the Raw Camps or Craigkelly, though traces of the umbilicus are quite distinct in several cases. According to Mr Etheridge, the Platyostomella has generic affinities to the Naticopsis, Platyostoma, and Stropho-

[1] Q.J.G.S., xxxiv. p. 18.

[2] Proceedings of Royal Physical Society, Session CIX. Mr Etheridge on a Small Naticiform Gasteropod.

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stylus, and has points of resemblance to the Ampullaria and some of the Neritinæ. It occurs, as far as yet known, only in the Calciferous Sandstone series, with a vertical range of about 2000 feet from the top of the Granton Sandstones up to the base of the Burdiehouse Limestone. It was first found in a band of thin shelly limestone known as the Buckie-fake, at Raw Camps Quarry, Mid-Calder. Later several specimens were got from a shale (?) at Drumsheugh, and Mr Bennie afterwards discovered the same shell in a band of shale at Craigkelly, near Burntisland. To these previous records we may now add the phenomenal occurrence of the little gasteropod in the Lepidodendron from Craigleith Quarry.

From the mere fact that the shell occurs in the interior of a fossil tree in an estuarine deposit, we are left in a tolerably safe position to infer that the gasteropod was able to exist and thrive in brackish, if not fresh water. We have already seen that the nests containing the Platyostomella must have been deposited in the tree at some time previous to the sand which filled up the interior. We have also seen the macroscopic and microscopic differences, and the probable difference in condition of deposition. If we keep in mind those facts, there is but little room to doubt that these calcareous nests containing the gasteropods are drifted material,—the remnants of some pre-existing deposit caught up by the tree at some period of its earlier history and partially washed out again. Fig. 2 shews the distribution of the nests in the interior of the Lepidodendron. At the bottom of the figure, the outline of the portion seen in section in Fig. 1, is indicated. This patch extends almost to the edge on the right hand side. This was the thickest of the deposits, and attains its maximum of an inch in thickness at the edge, gradually thinning *inwards* towards the centre. Supposing for a moment that the gasteropods were washed into the Lepidodendron after it had taken up its final resting-place in the sand, we would surely expect to find the point of maximum thickness towards the centre of the tree. To illustrate better what I mean, suppose a number of small objects like shells to be shot into a cylindrical body by the agency of running water, and under the force of gravity. After the operation the bodies will be found to occupy a central position in the lower half of the cylinder, and to arrange themselves in a more or less continuous line parallel to the axis of the cylinder. If the rest of the interior be now filled up with a different substance like sand, and the whole submitted to pressure from above, the bodies will be found in the same relative position with their maximum thickness in the centre and gradually thinning off towards both sides. Figs. 3 and 4 shew what is

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meant. If subjected to pressure from above, Fig. 3 will yield such a result as is indicated in Fig. 4. Now if we restore the fossil Lepidodendron, it is obvious that the gasteropods were in the position represented by the shaded portions of Fig. 5 before the sand was deposited in the interior. If the squashing of the tree be due to subsequent causes, it is clear that the nests could not have taken up such a position in the ordinary course of deposition. There seems but one way to account for their curious situation. They must have been clinging to the interior of the tree in practically a solid mass; otherwise the law of gravitation would have insisted on them taking up a more central position. Another point worthy of observation is, that the shells are equally distributed throughout the nests. If we keep in mind the curvature of a hollow tree, we would expect to find them in greatest numbers in what was then the lower side.

The material on which the shells lie, as already observed,

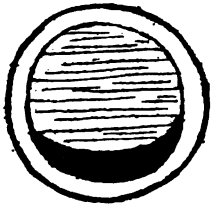

FIG. 3.

FIG. 4.

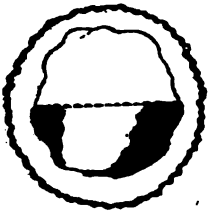

FIG. 5.

forms a tenacious mud which hardens on losing its moisture. If such a deposit were washed out again from the interior of a hollow tree, only those portions that were well within the interior and were harder and more tenacious would remain behind. A tree drifting any distance is bound to lose the greater portion of material carried away with it by the buffeting and lapping action of the waves to which it is subjected in its journey seawards. We have even geological records of material dropped in this way. I need hardly cite the case of *Pupa vetusta* and *Zonites priscus*, both of which are land shells, and which we know must have been dropped by drifting vegetable matter into the muddy bottom of shallow water.

These nests in the Lepidodendron I take therefore to be the remnants of some earlier deposit which had been washed out again, and the probable extent of the original deposit to be represented by the line in Fig. 5. Of the earlier history of the tree we can know but little. We know it grew on the muddy

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banks of a river and attained a considerable size; then decayed and was carried seawards in a south-westerly direction by the river as far as its great estuary or delta. The rest we must furnish for ourselves. Palaeozoic rivers were in nowise different from those of to-day. Every river of any size is constantly bringing floated timber from its higher reaches, especially during a spate. Such drifted material must occasionally at least, retain relics of its previous history. The drift can seldom be one continuous process. An awkward body like a tree will get at times into shallows or may lie buried in mud on the banks till the next flood causes it to resume its journey. This process may be repeated, until at some future time a large spate will carry it right out seawards, when it will get covered up with sand and silt, along with any land-derived or fresh-water organisms it may have retained. Such may have been the fate of the Lepidodendron from Craigleith. It may have lain in a decayed condition in a shallow or on the muddy banks of the river, and a spate with its muddy turbulent water shot into it a jumbled, confused mass of shells, pebbles, &c. The strength of the current would be sufficient to cause it to move onwards with its load, and in time to lose most of the material again, when it would become lighter and float away out seawards. Those parts alone which were well within the interior and in a condition to resist such treatment would survive to the last.

Looking now to the previous records of the shell. The first specimens were found by Mr Bennie at the Raw Camps Quarry in a thin band of shelly limestone and shale immediately underlying the Burdiehouse. This latter deposit is admitted by almost all geologists to be a fresh-water or estuarine limestone; and from the fact that this shell occurs in a thin bed which contains no marine fossils at its base, on the absence of other evidence, it seems not unreasonable to suspect the fresh-water or brackish origin of the Raw Camps Platyostomella. The next specimens were got from Drumsheugh, near the Dean Bridge, in a shale (?) at the top of the Granton Sandstones which we may regard as the borderland between estuarine and marine. The shell also occurs at Craigkelly Quarry in a band of shale. This quarry lies near Burntisland, to the west of the volcanic neck known as the Binn. At this locality it is associated with *Spirorbis pusillus*, which would indicate marine conditions. But the Craigkelly Platyostomella differs considerably in morphological characters from that at Raw Camps, so much so that Mr Etheridge hesitated whether to allow them to pass as one and the same shell or not. Even admitting the identity to be established, the difference of form may indicate a difference in habit of this particular gasteropod. The Platyostomella pro-

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bably resembled in habit the Hydrobia of which fresh water, brackish, and marine forms are known. If so, this form in the Lepidodendron of Craigleith Quarry along with that found at Raw Camps, would seem to be the fresh-water variety of the Platyostomella, and the Craigkelly the marine.

Although the Lower Carboniferous rocks of Scotland are so rich in drifted material, it is surprising that little or no trace of land-derived or fresh-water organisms has yet been recorded from among our plant remains. This may be due to two reasons. Much of the drifted material may have come from long distances and lost anything it may have transported, before being embedded in the sand or silt. Or perhaps it is due to the tendency of collectors to pass over such common fossils as Lepidodendroids, Stigmaria, &c., without examining their internal structure, to see if they can give us any further details of the world's life history. It is only thus we can hope to know many of the tinier creatures of the earth, and to fill in the vacant little blanks in the long record of the rocks.

Explanation of Plate.—The plate is from a photograph taken of portion of the Lepidodendron containing the shells of Platyostomella. The view is of the interior of the tree, the bark being on the side remote. The jumbled appearance of the shells in the deep coloured nest, as well as the unconformity between the laminæ of sand and the nest, are well seen. The original is now deposited in the Museum of Science and Art, Chambers Street, Edinburgh.

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XXXVI.—*On Apophyllite from Cape Colony.* By JAMES CURRIE, Jun., M.A., F.R.S.E. (Plate XIV.)

(Read 18th March 1897.)

THROUGH the courtesy of Mr Gardner F. Williams, the General Manager of the De Beers Mines, I was permitted during a short visit I paid to Kimberley in 1889 to examine the "floors" upon which the blue ground of the Company is placed for weathering, and the heaps where the rejected material is deposited. Most of the minerals to be seen there are of course derived from the diamantiferous breccia of the volcanic neck, and few of them, as has been remarked by Professor Bonny and others, show recognisable crystal faces. Perhaps the commonest of the minerals thus occurring with the diamonds are olivine, chrome diopside, biotite, and pyrope.

Besides these minerals there are others which are obviously not derived from the neck but from the exterior melaphyre or basalt, and among these is Apophyllite in very distinct crystals. I paid no particular attention to the specimens at the time, but on examining them lately with more care it seemed to me that they were worthy of notice, especially as South Africa does not appear as a locality for this mineral even in recent and exhaustive works on mineralogy, and also because the specimens exhibit some uncommon forms.

Apophyllite appears to occur at Kimberley in two similar but distinct types. In the first the transparent and colourless crystals are well defined, lining cracks in the decomposed rock, upon which they are implanted directly, with the basal pinacoid generally vertical to the surface. The forms are c (001), a (100), m (110), p (111) σ (211), (Plate XI., Figs. 1 and 2). Sometimes the crystals are cubic in appearance by the reduction of p to a small triangle truncating the solid angles. On the other hand the habit is even more frequently thin tabular, the thickness being one-fifth or less of the length, and in this case a may be represented by a small lozenge. The crystals occur up to 15 mm. in length. When they weather, they whiten and break up into foliæ parallel to the basal pinacoid.

The second type I observed only on detached and broken fragments, but the crystals seem to have been 3 or 4 cm. across; they are thin tabular parallel to c. The forms are much more numerous in this case, but most of the faces are still confined

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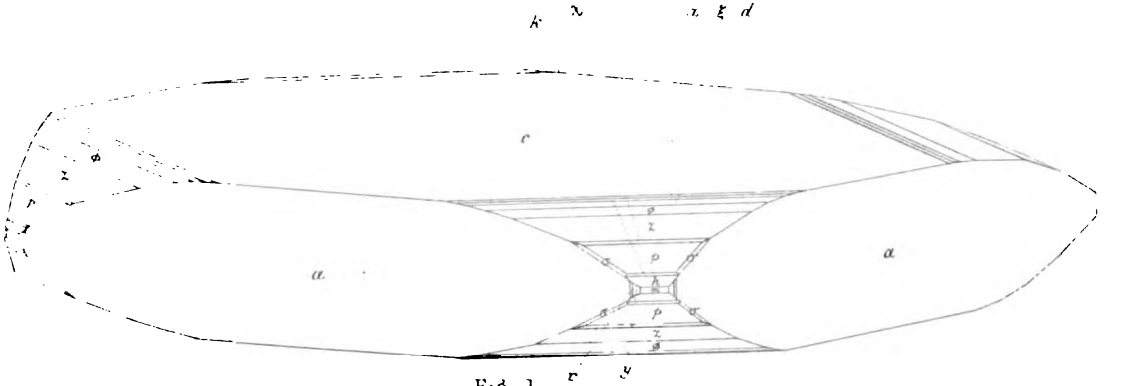

Fig. 1

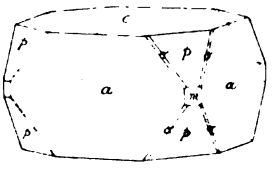

Fig. 2

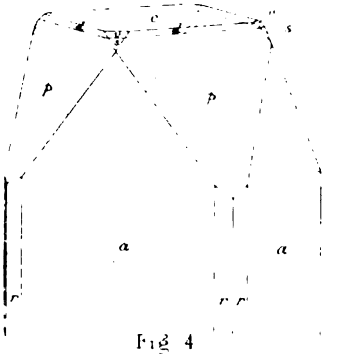

Fig. 4

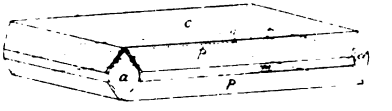

Fig. 3.

Jas. Currie, del.

M'Farlane & Erskine, Lith.rs Edin.r

APOPHYLLITE. Figs. 1–3, Kimberley, S. Africa. 4, Portree

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to the zone $\{cp\}$. Between z and c there are no fewer than four. These are extremely narrow and are repeated so frequently that they are not easy to determine accurately. The combination seems to be c (001), a (100), m (110), y (210), r (310), p (111), x (1·1·10), ξ (119), d (115), ϕ (227), z (113), χ (223), k (332), h (221), σ (211), (fig. 3), with c, a, z, p as the predominant forms. The specific gravity is about 2·33.

The faces a and z are strongly striated; the former perpendicular to c, and the latter parallel to it: c itself is striated in an irregular manner parallel to the edges c/a and c/p.

In general habit these crystals suggest the Apophyllites of the Seiser Alp, and, at least in the second type, contrast strongly with the comparatively simple forms which are familiar to us from the igneous Tertiaries of Western Europe, where the most usual combination is *acp*. By far the most complicated crystals I know of in Scotland were observed by myself at Rudha na h-Airde Glaise, near Portree in Skye. These occupied a small druse along with radiating mesolite, on which they are disposed. The forms of Apophyllite there present are c (001), a (100), r (310), p (111), d (115), v (105), s (102)—the two last being extremely minute faces, identified by Professor Heddle. For the sake of comparison a drawing is given of one of these Portree crystals (Fig. 4). They measure about 3mm. across.

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XXXVII.—*Incipient Metamorphism in the Harlech Grits.* By EDWARD GREENLY.

(Read 18th March 1897.)

FOR more than half a century, ever since the early classic labours of Sedgwick and the masterly exposition by Ramsay of the work of the Geological Survey, the name of the Harlech Grits has been familiar to geologists as that of the rocks which rise along the axis of the great anticlinal of Merionethshire. Their Cambrian age has never, so far as I know, been called in question—indeed, the term "Harlech Series" has often been used as synonymous for the Paradoxides zone of the Cambrian system, though in view of their almost unfossiliferous character, this seems undesirable.

Their thickness is very great, the estimate of Sir A. C. Ramsay being from 7000 to 8000 feet; the base moreover being unseen, although slaty beds are more abundant in the lowest portions exposed. They are wonderfully thick-bedded; single beds reaching 8, 10, or even 12 feet; and very hard: and, between the crown of the anticlinal and the coast, rise into a range of mountains about 2400 feet in height, whose bald tops and step-like escarpments will compare, for expanse of grey and barren rock, with the Archaean Gneiss of the North-West of Scotland.

Lithologically, the Harlech Grits are for the most part greenish greywackes, generally coarse, and often pebbly, though sometimes compact, weathering "brown-crusted," and very hard when undecomposed.

On a fresh fracture they have a singularly ancient and altered look—an observer accustomed to such a rock, for instance, as the Torridon sandstone, would never suppose these grits to be of later date than the almost undisturbed pebbly sandstones and ripple-marked shales of that remarkable formation. There, every grain, every pebble is distinct, almost as if it were of yesterday; here the outlines of the grains are hazy, and the rock has a somewhat igneous, diabase-like, aspect. This was noted, and is well described by Ramsay: "The rock has often a semi-crystalline aspect, perhaps due in some cases to the original angularity of its component grains, and in others to the partial effects of what is termed metamorphic action" (Geol. North Wales, ed. ii., p. 19).

In examining one or two slides in my possession, which had been cut merely as examples of the group, the textures which

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give rise to this appearance were well seen, and seem to me to be of some interest.

The component minerals identified are quartz, felspar (often plagioclase), chlorite, epidote, iron oxides, calcite, white mica, hornblende (?), zircon, apatite, and tourmaline. The original clastic grains include, besides the abundant quartz and felspar, fragments of andesites, felsites, and granitoid rocks, as well as a foliated quartz-mosaic rock probably belonging to a schistose series. They are moderately rounded.

By ordinary transmitted light, the same haziness of outline is observable as in hand-specimens, and the green colour is seen to be due to chlorite and epidote.

Between crossed Nicols much more becomes evident. In slides of the Torridon sandstone, the outlines of the grains, however angular, are those of attrition, and the outline seen between crossed Nicols coincides with that in ordinary light. Each grain is bounded by clear, smooth curves, broken only by few angles, re-entering angles being rare and moderate. In the Harlech Grits, on placing a slide between the Nicols, the grains appear to have been suddenly "frayed out" all round, producing an effect of peculiar confusion after having looked at the Torridonian grit. This is due to the fact that the margins of the grains are composed of an intimately interlocking mosaic, the elements of which have different optical orientations ("granulitization" of some authors). Some of these mineralogical elements, moreover, are in mineral union with material that lies outside the periphery of the grain as seen in ordinary light. In some cases the grain has been encroached upon by the matrix, in others it appears to have grown outwards to it; but of these points it is somewhat difficult to be really sure. The matrix itself is also a mosaic.

Now this structure is characteristic of crystalline schists; it is the structure of the "Moine Schists" of the N.W. Highlands, of Hornblende-schists of the Scourie Dyke type, and many other well-known types. A slide from the epidotic grits of the Highland "Green Beds" near Dunoon shew the same structural characteristics in a high degree; and another from one of the grit lenticles occurring in the schists of the S.E. of Anglesey, recently described by the author (Geol. Mag., Dec. 1896), also possesses it. The Harlech grits, however, approach much more nearly to the characters of these Anglesey rocks than might have been expected from the associations of the latter.

Returning to ordinary light, the chlorite of the matrix is seen to be fairly well crystallised in small green blades or plates, which are arranged for the most part in rows, with their longer

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axes and cleavage planes lying across the narrow inter-spaces between the pebbles. Very often they form a radiating halo all round a grain or pebble. In the slides in my possession they

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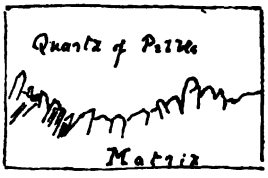

Nº 3.

cannot be seen to have any general orientation or foliated arrangement. Now, when these radiating halos are examined with a high power, it can frequently be seen that fine green plate-like and acicular crystals pass out from the surrounding matrix and penetrate into the body of the quartz of a pebble (Figs. 1, 2, and 3, which were drawn by hand from the microscope), retaining perfectly their own crystalline forms. The quartz of the pebble is in each of the drawings, and in many others, not a mosaic aggregate, but a mineralogical unit. The original water-worn boundary of the pebble has therefore, in these cases, wholly disappeared, the existing boundary being composed of a kind of *chevaux de frise* of green acicular crystals projecting into clear quartz. Many of the finer of these green needles have a much higher double refraction than chlorite, and are probably a green biotite or a pale hornblende with a low extinction angle.

The epidote occurs in small irregular granules in the matrix, in which also are numerous crystals of magnetite (Fig. 4), which are not only idiomorphic, but have often several sharp re-entering angles. (Both chlorite, epidote, and magnetite occur also in the included igneous fragments, but merely in the manner common in altered andesitic rocks, and calling, therefore, for no remark.) Some grains of Tourmaline also, which were probably clastic in origin, have been enlarged by outgrowth into crystalline groups adapted to the form of the interspaces in which they lie (Fig. 5).

Fig. 4.

Fig. 5.

It is manifest from the foregoing facts that there has been considerable mineralogical readjustment of the constituents of these rocks, and that not merely of the more easily altered

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matrix; but of the marginal portions of the quartz-pebbles themselves, between which and the matrix mineral and chemical interaction has taken place, resulting sometimes in granulitization of the quartz, sometimes in a penetration of quartz that still retains its integrity by the ferro-magnesian constituents of the matrix.

Comparing with other altered sedimentary rocks, the epidotic grit from Dunoon considerably exceeds them in degree of alteration; the granulitic mosaic extends more deeply into the quartz-pebbles, so that the smaller ones are wholly granulitised, the mosaic itself being coarser in texture, while the ferro-magnesian constituents are more perfectly formed and larger, including good crystals of brown mica. The rock is indeed rather a crystalline schist with surviving original structures, than merely a schistose grit. A highly-sheared specimen of Torridon sandstone from near Kinlochewe, however, though full of sericitic mica, does not exceed, possibly does not equal, the Harlech Grit with regard to the re-crystallisation of its constituents, the structural type being also very different. And, as above stated, the degree of alteration in a small gritty lenticle, embedded in highly schistose material from S.E. Anglesey, is but a little higher.

The comparisons just now made, moreover, lead to certain considerations bearing upon the interesting question of the causes which have induced this process of re-crystallisation in the Harlech Grits.

The altered rocks with which we have just compared them are all more or less foliated, and some very markedly deformed by shearing stresses. But in these slides and specimens from Harlech, no deformation or parallel structure of any kind is discernible. The plates of chlorite have no foliated arrangement, indeed, the only marked arrangement is one radial to the larger pebbles, nor are the other idiomorphic constituents elongated in one direction more than in another. And, further, it is remarkable that the felspar pebbles have been less affected by the metamorphic processes than those of quartz, and that those of Felsite and Andesite appear to be unaffected altogether. There are pebbles of Andesitic lava, full of delicate, lath-shaped felspars, which show no trace of deformation, even at the edges, their delicate polysynthetic twinning continuing to the very point of contact with the matrix; while pebbles of quartz, almost in contact with them, have their margins granulitised and penetrated by plates of chlorite.

These facts are certainly suggestive of contact—metamorphism. But the specimens described were taken from near Maes-y-garnedd and Moelfre, a mile or so to the S.W. of the

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Pass of Bwlch Drws-Ardudwy, where no igneous rocks are indicated on the one-inch map but two small basic dykes, and those nearly half a mile away from the nearest point. Moreover, it is exceedingly unlikely that large igneous masses are concealed immediately below, for although certain felsitic rocks do appear about the crown of the anticlinal, the district from which the specimens are taken lies in a synclinal axis, between the mountain range and the sea, and is trenched by deep transverse valleys, in none of which do any such igneous rocks appear.

On the other hand, though the slides exhibit no signs of deformation or foliation, undulose extinction is exceedingly common in their quartz-pebbles. The whole district also has been, as is well known, affected by movements which have produced folds of gigantic vertical amplitude, and the finer beds in the series have been converted into slates.

It seems reasonable, therefore, to refer the mineral changes in question to dynamical causes.

And while these causes have, in the rocks of finer grain, produced the usual mechanical effects; it would seem that the resistance offered by these thick and massive beds of grit converted the energy, according to known laws of transformation, into equivalents of molecular movement, which, without any process of mere mechanical crushing, have yielded these beautiful and delicate effects of re-crystallisation.

Geological speculation at present shuns, and wisely, terms, such as "selective metamorphism," associated, as they are, with very rash applications of former metamorphic theories. But it is easy to see that, granted a process such as we have supposed, a natural mineral selection must take place; and, as the process is not mechanical, but chemical, the survivorship will be determined, not by mere hardness, but by chemical affinities. Quartz we know is affected quite easily by chemical actions of common geological occurrence, and so also are the ferromagnesian minerals, while the re-crystallisation of felspar is characteristic of a high degree of alteration. The apparent anomalies, therefore, in the behaviour of several of the constituents above mentioned are consistent with the suggested explanation.

These remarks are based merely upon the study of one or two slides cut from specimens collected some time ago. But a comparative petrological study of these old Cambrian grits, founded upon field-evidence, would probably yield results of considerable interest to students of many metamorphic rocks whose geological age is still unknown.

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XXXVIII.—*Notes on a Borehole through the Rocks of the Calton Hill.* By J. G. GOODCHILD, H.M. Geological Survey, F.G.S., F.Z.S., Curator of the Collections of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art.

(Read 18th March 1897.)

WITHIN the last few months a borehole in search of suitable water for brewing purposes has been sunk close to the Calton Hill at Abbey Hill. The site of the well is about one hundred and fifty yards due east of the Calton Tunnel, and about fifty yards south-west of the Abbey Hill Viaduct on the North British Railway; that is to say, it is about a quarter of a mile east-north-east of the Waverley Station at Edinburgh. A borehole was sunk several years ago, for similar purposes, at the St Ann's Brewery, which lies about two hundred yards to the east-north-east of the one specially under notice. To prevent confusion regarding which borehole is meant, the older one will be referred to here as Abbey Hill Borehole No. 1, while the borehole under notice will be referred to as No. 2 of the same locality. The sequence proved in No. 1 was recorded in the *Transactions* of this Society by Mr John Henderson. It will suffice for present purposes to state that the borehole was sunk to a depth of rather over five hundred feet, nearly the whole of which was in black shale, which lay directly upon volcanic rocks of the same type as the top beds seen on the Calton Hill. No one doubts that these Abbey Hill shales are the same as those which are seen to overlie the lavas of the Calton Hill in the neighbourhood of the Regent Terrace, the Regent Gardens, and the Royal Terrace, and which were also laid bare in the railway cutting at Abbey Hill, where they were seen to overlie the volcanic rocks in which the tunnel itself is excavated. They are doubtless also the same black shales whose existence at Holyrood was made known by Mr John Henderson, and which have been called the Holyrood Shales. There does not seem much reason to doubt that these same Abbey Hill shales underlie and graduate upwards into the Granton Sandstone Series, beds in which were at one time worked in various quarries around Lochend Loch. They are thus perfectly distinct in position from the Wardie Shales, which Mr John Henderson has shewn to overlie the Granton Sandstone, and

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which graduate in their turn into the sandstones of Hailes and Redhall.

The prevalent dip of the Lower Carboniferous Rock around Abbey Hill is east-north-easterly at angles varying from 15° to 25°. It was therefore to be expected that any borehole lying to the west of No. 1 would reach the volcanic rocks at a lesser depth than in that locality. This was the case in No. 2 borehole; but what the precise depth was does not seem to have been recorded; it was probably only a few feet. The borehole certainly entered the volcanic rocks at a short distance below the surface, where alternations of lavas and tuffs, with occasional bands of rocks of sedimentary origin, are stated to have been met with down to a depth of 750 feet from the surface. No record of the details of these appears to have been kept by anyone, and such of the cores as I had an opportunity of inspecting were not identifiable in regard to their position. They were certainly andesites, with the exception of the lowest, which was basaltic.

Immediately below the basalt lava at the base of the series was proved a considerable thickness of light-coloured sandstone and flags, containing much carbonaceous matter, and very similar in general character to the type seen at Craigleith Quarry. This discovery at once served to explain the occurrence in the foundations for the new North British Railway Hotel of a sandstone of exactly the same type. In this latter sandstone were many fragments of lepidodendroid trees. A sandstone whose description well accords with that under notice was proved many years ago in digging the foundation for the Regent Arch. It may be remarked here that no such rock has yet been seen on Arthur Seat. Its place should be somewhere on the western slopes of the escarpment below the rock of the Long Row—assuming that this rock is really a lava, and contemporaneous with the lowest basalt lava seen below the Calton Gaol. The base of this sandstone was reached a little below at the depth of 800 feet. At this point the boring apparatus brought up the top of a thick bed of black shale, of which the upper 15 feet contained no trace of any volcanic material. At that depth a thin band of tuff was found interstratified with the shale. At 820 feet the borer proved the existence of one or two thin bands of finely striped horny textured limestone, with some few bands of chert. The rock bore the closest possible resemblance to an old geyserite, and like that rock showed, in the most beautiful manner, evidence of contemporaneous crumpling and contortion of the laminæ, due, perhaps, to the effects of the violent earthquakes which usually accompany volcanic eruptions. A short distance below the shale a thin band of sandstone was seen,

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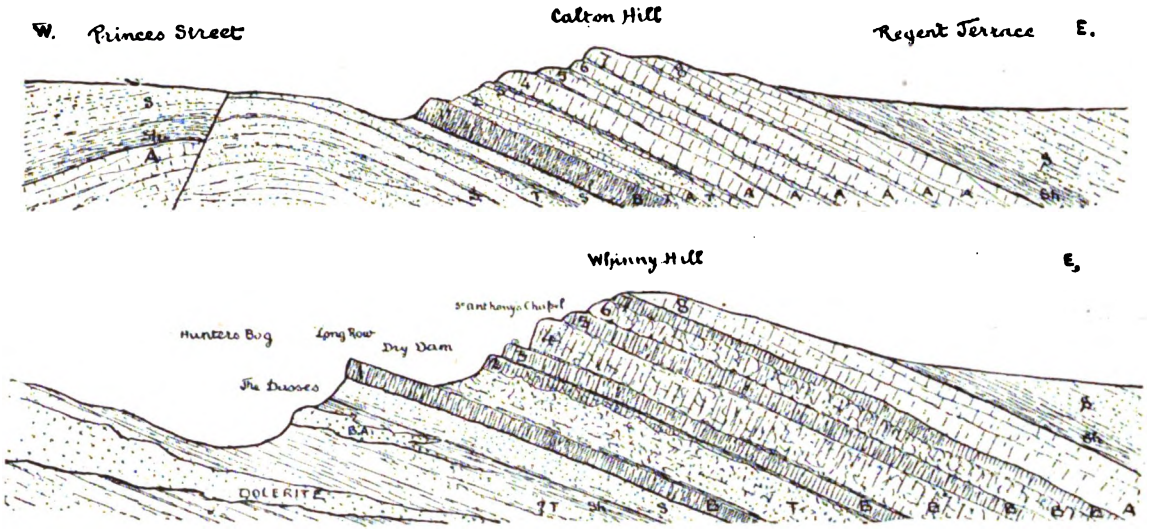

Diagram Sections across the Calton Hill and the Northern End of Arthur's Seat

The rocks of the Calton Hill are copied from Fig 11A of Geikie's 'Ancient Volcanoes of Gt Britain'

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which in its turn gave place to more tuff. Before noticing this further, it may be well to mention here that rocks very similar to those just described occur above and below the horizon on Arthur Seat, invaded by the andesitic basalt of the Dasses. They have often been exposed in sections between Castle Hill and the Canongate. There can be no doubt that they represent what has been called the Cement Stone Group in one part of Scotland, and the upper part of the Ballagan Beds in another. The tuffs just referred to as underlying these Ballagan shales consist of rapid alternations of fine volcanic ejectamenta, of sandstone mingled with tuff, and of very thin bands of sandy shale. The alternations are very close, and bring before the mind most interesting evidence of alternate periods of quiescence and eruption, evidently this latter being due to the action of a volcano situated at some little distance from the site under notice. Rocks of this type were proved to a depth of 872 feet below the surface. If these rocks exist on Arthur Seat their place will be found somewhere in the low ground in and around Hunter's Bog. Rocks of this same type were proved in the Ballagan Beds in the High Street of Edinburgh, about a hundred yards to the east of the Tron Church. Mr Peach informs me that similar rocks were reached in sinking a deep foundation in Princes Street at the south-west angle of the Register House, and I noted the same alternations of tuff, shaly beds, and sandstone in the foundation for Jenner's new shop in the same street.

Further boring pierced alternations of reddish and greenish sandstones and shales identical in character with the rocks formerly worked at the Camstane Quarries on the east slopes of Salisbury Crags, and which are so well displayed in the well-known and oft-visited quarries at the north end of Salisbury Crags. These represent the lower part of the Ballagan Beds of Glasgow geologists. No dolerite was met with, whence we may conclude that the great mass of the Salisbury Crag Dolerite seen at the Cat Nick does really thin away to nothing as it trends north-eastward, as it does also to the south-east. This lends further confirmation to the view that the rock of Salisbury Crags is a great intrusive *wedge* of dolerite, with its thin edge directed towards the east. The lower Ballagan Beds were found to graduate downward into sandstones of the type so well seen at Craigmillar, along the Radical Road at the foot of Salisbury Crags, and again on the southern slopes below the parade ground at Edinburgh Castle, and also above the red sandstone seen in the Suburban Railway Cutting just south of the Station at Craiglockhart. They contained the same flakes and angular patches of carbonate of lime, which appear to mark the breaking

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up of thin, chemically-precipitated deposits formed in the shallow waters of the old lagoon in which these rocks were laid down, and which carbonate of lime, on slightly lower horizons, takes the form of the well-known cornstones of the higher parts of the Upper Old Red Sandstone. They afford interesting evidence of the change of climatal conditions and of the advent of vegetable organisms at the close of the period of desert conditions to which the peculiar character of the Upper Old Red Sandstone is due. In rocks of this Craigmillar Sandstone series the borehole was stopped, suitable water being obtained at a depth of 930 feet from the surface.

I am much indebted to Mr Robert Henderson, the well-sinker, for information respecting this interesting boring, and for allowing me to take specimens of the chief types of rocks passed through in the course of the work. These cores are now preserved in the Geological Gallery of the Edinburgh Museum of Science and Art.

About the importance of the present section no geologist who has attempted to work out a satisfactory map of the Geology of Edinburgh can have any doubt. It certainly throws a flood of light upon many points which have lain in the utmost obscurity until now; and it will do much to enable us to understand more than has hitherto been possible of the relations of the various exposures which have been from time to time laid bare in the faulted and geologically obscure part of Edinburgh lying between the Waverley Station and the grounds of Holyrood Palace. The borehole has proved that in Edinburgh, as in the west of Scotland, volcanic rocks occur in the upper part of the Ballagan Beds. It has proved the existence of Ballagan Beds of the normal type here, and has shewn us conclusively that these beds overlie the calcareous breccias of Craigmillar and Salisbury Crags. English geologists fresh from the study of the Lower Limestone Shale of the North of England will at once (as the members of the Geologists' Association lately did) recognise the Ballagan Beds and the Craigmillar Sandstones as together representing that subdivision of the Lower Carboniferous Rocks.

Amongst the many interesting questions suggested by the study of this borehole is one connected with the relation that subsists between the volcanic rocks of Arthur Seat and those of the Calton Hill. It has usually been considered that these two masses

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of volcanic rocks represent segments of the same volcano dissevered by one or more powerful faults. In a general way, no doubt, that view is correct; but it has long been recognised that the lithological type of the lavas on the Calton Hill does not accord with that on Arthur Seat. On the Calton Hill the lowest lavas, those on which is perched the gaol, are the only basalt lavas there—all the higher beds being typical andesites. On Arthur Seat all the lavas, except the very topmost bed, are basalts, that bed being an andesite of the same type as that which makes up nearly the whole of the lavas on the Calton Hill. From the consideration of this point, it is clear that the two masses cannot possibly have come entirely from the same vent, though they may very well have flowed from vents closely adjacent, in exactly the same manner as so often happens with volcanoes at the present day. Nobody seems to have thought of attempting to determine where the Arthur Seat type begins and the Calton Hill type ends. The cores of volcanic rocks from the well section (except the very lowest) had nearly all been thrown away before I had an opportunity of examining them; but those I did see were certainly of the Calton Hill type—that is to say, they consisted of alternations of tuffs and thin sandstones with lavas of an andesitic type, based upon a thick mass of basalt. To put this statement into another form—the well section has proved that the Calton Hill type of volcanic rocks extends south-eastward nearly to Holyrood. Where then is the line of separation to be drawn between this one set of lavas and those of Arthur Seat?

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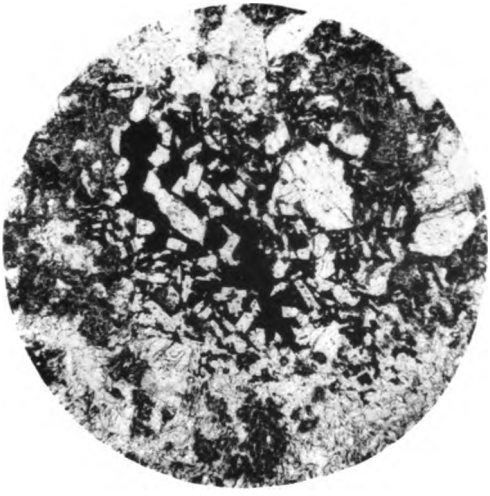

Fig. 1.—Ailsyte, Ailsa Craig.

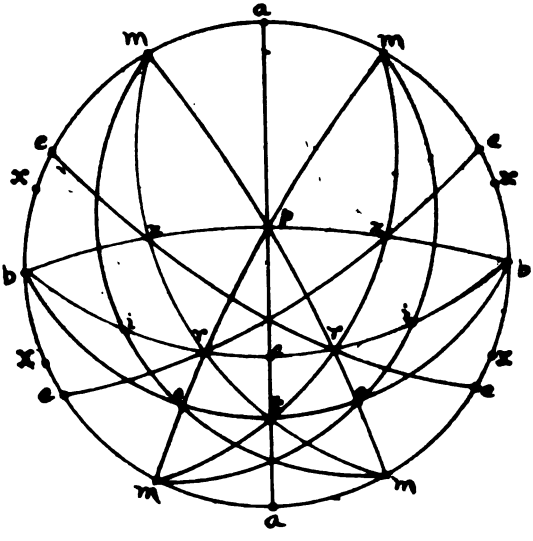

Fig. 2.—Stereographic Projection of Riebeckite.

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Fig. 1

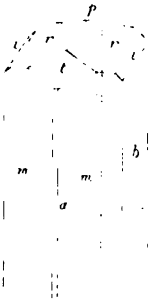

Fig. 2

Fig. 3

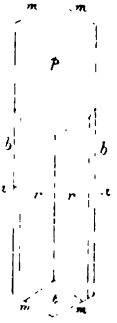

Fig. 4.

Fig. 5

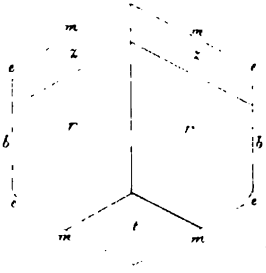

Fig. 6.

M. F. Maddie, del.

M'Farlane & Erskine, lith.

RIEBECKITE.

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XXXIX.—*On the Crystalline Forms of Riebeckite.* By Professor M. F. Heddle, F.R.S.E. (Plates XV. and XVI.).

(Read 15th April 1897.)

About the year 1884, Mr James Blackwood, at that time far and away the most enthusiastic petrographer in Scotland, sent me sections of the red and grey varieties of the microgranite of Ailsa Craig, then termed syenite. He said that I would find microscopic nuggets of gold in the grey rock, and he asked my opinion as to the nature of a mineral therein, which he said could not be hornblende or any species that he was familiar with.

To my astonishment I found that he was correct as regarded the gold, five of his sections showing minute specks of this metal, the largest of which was about ·006 mm. I reported, however, that I could say nothing as to the dark mineral, as it differed from hornblende and from everything else that I had ever seen.

About a year after this, Mr Blackwood wrote me that he had sent the rock to Professor Judd, who pronounced the mineral to be Chloritoid. It so happened that I had myself some years before obtained exceedingly fine specimens of Chloritoid from the schists of Hillswick in Shetland, and had determined the mineral by my own analysis. I had also made sections of it, and as these could not be said to comport themselves under the microscope in any respect as did the Ailsa mineral, I had to report that I could not range myself with Professor Judd in his finding.

Mr Blackwood then submitted specimens to M. Lacroix, who had made a careful study of Chloritoid, and who agreed with me in stating positively that the mineral did not belong to this species. Professor Judd, however, adhered to his opinion, and in 1886, in a footnote to a paper by him on the Volcanic Rocks of the North-East of Fife (Q. J. G. S., 1886, xlii., 428), he says: "Chloritoid . . . is by no means rare among the Scottish rocks. I find it to occur very abundantly in the interesting rock of Ailsa Craig, for opportunities of studying which I am indebted to Mr Blackwood of Kilmarnock."

I thereupon drew up and sent to Mr Blackwood a scheme showing the differences between the two minerals, which enabled me to say—

"I give it as my opinion without hesitation that the green

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mineral in Ailsyte is not Chloritoid. Chloritoid has been written upon by thirteen authors from sixteen localities, and has never by any author been referred to other than sedimentary rocks."[1]

Two years later, specimens from Socotra, which had been described by Professor Bonny as Tourmaline, were analysed by Sauer (Zeitschr. d. d. geol. Ges. 1888, 40, p. 138), and by him rightly referred to a new soda-bearing member of the Amphibole group, under the name Riebeckite, from Dr Emil Riebeck, the collector of the Socotra specimens.

In 1891, Mr Teall announced (Min. Mag. 1891, 9, 220) on satisfactory optical grounds that the mineral of Ailsa Craig was Riebeckite, and its identity with Sauer's species was thus settled. He gives a good description of its occurrence, and the only part to which I take exception is his characterisation of the structure as "spongy." In reality the mineral here affords a characteristic example of ophitic structure, the spaces between the felspar crystals being filled up by interstitial Riebeckite, the different portions of which are in optical continuity. This structure is well shown in Plate XV., Fig. 1, which is taken from a microphotograph of one of my sections by Mr William Forgan. The rock seems to be distinct enough to warrant the application to it of the specific name of Ailsyte, which was bestowed upon it by Mr Blackwood. Ailsyte may be defined as a microgranite with a considerable amount of Riebeckite ophitically developed in it. This mineral appears in distinct crystals in the druses only, and the rock thus differs from the granite of Socotra where the Riebeckite occurs as small prisms in the mass of the rock.

Since Mr Teall's identification of the Ailsa mineral, Riebeckite has been reported from two other Scottish localities, the "syenite" of Meall Dearg[2] (one of the Red Hills of Skye), and the porphyrytic felsite of the Eildon Hills[3] in Roxburghshire. The latter is an unusual rock for this mineral, and the identification, which is based altogether upon certain optical grounds, does not appear to be quite satisfactorily established.

In the summer of 1893 my confrère Mr James Currie and I were endeavouring to unravel some of the geological puzzles which occur along the coast of Ayrshire near Lendalfoot. A visit of some hours was at that time paid to Ailsa Craig with a view to obtain characteristic specimens of its rock. Mr Currie was then particularly fortunate in obtaining well-developed crystals of Riebeckite large enough for the determination and

[1] Since that date I have seen only three further notices of the occurrence of Chloritoid, and these also relate to metamorphic rocks.

[2] Teall, quoted by Geikie, Q.J.G.S., l. (1894), 219.

[3] T. Barron, Geol. Mag., iii. (1896), 371.

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delineation of the crystalline form. The usual size of these was about 3 mm. long by 2 mm. broad, but some very ill-defined crystals were as much as 2 cm. across. Figs. 1 to 4 of Plate XVI. represent some of the forms obtained upon that occasion and were drawn by me soon after. A further visit to the rock in 1895 enabled Mr Currie and one of his sisters to obtain the examples shown in Figs. 5 and 6, the former showing characteristic face sculpturings.

The edges are sometimes slightly rounded, but otherwise the crystals are sharp and well-defined. The form is very close to that of Hornblende, and, although there is no marked elongation along the axis of *c*, the crystals are of the actinolitic type.

The combinations observed were *mbrtpa*, *mbrtpai*, *mbaic*, *mbrtpi*, *mbrt*, *mbrtze*, and *mbrtzeo*. The accompanying plate (XVI.) represents all of these except the last. The faces *z*, *e*, and *o*, occurred only on crystals associated with those of the simplest form, and in both of the cases observed the crystals showing these faces were hemihedral.[1]

Up to that time the only crystalline forms reported had been the actinolitic faces *b* and *m* from the Socotra locality, but in 1895 Professor W. J. Sollas described specimens from loose blocks in the glacial deposits of Northern Ireland (Proc. R. I. A., 3rd series, III., p. 516), from which he was able to determine the crystallographic elements of the mineral, and on which he identified the following forms:—*b* (010), *m* (110), *x* (150), *r* (011), *t* (101), *p* (101), *z* (121). Of these forms all but *x* were observed on our Ailsa Craig specimens, which bore in addition the new forms *a* (100), *c* (001), *e* (130), *i* (031), and *o* (121). The position of all the observed forms is shewn on the stereographic projection (Plate XV., Fig. 2) kindly drawn for me by Mr Currie.

The typical combination appears to be *mbrt*, with subsidiary modifications of edges and angles: one druse found was occupied almost entirely by crystals showing these four forms only. There would seem to be little room for doubt that Professor Sollas's specimens were derived originally from the Scottish locality.

Although minute, the appearance of the little druses which carry the Riebeckite in the microgranite of Ailsa Craig is very pleasing,—the dark green, almost black, crystals being set off by doubly terminated crystals of quartz, of which there is a very considerable quantity in the rock. These in turn are surrounded by minute pearly-lustred crystals of what appears to be Murchisonite.

[1] In order to show the relation to Hornblende, the lettering adopted is that used by Dana (6th ed.).

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XL.—*Notes on the Geology of the Isle of Arran.* By W. GUNN, F.G.S., H.M. Geological Survey. Communicated by permission of the Director-General of the Geological Survey.

(Read 15th April 1897.)

THE Isle of Arran has long been looked upon as the happy hunting-ground of geologists, the number and variety of its rocks, both igneous and aqueous, making it almost an epitome of the geology of Scotland. The northern part of the island, with its granite core and ring of metamorphic rocks, has been fairly well represented on the geological maps, but the plexus of intrusive rocks in the southern part has been till lately simply a chaos, and no serious attempt was made to resolve it. . . .[1]

Schists.—The foliated schists which nearly surround the granite are by far the oldest rocks in the island, but their exact age is not known. They are a part of the great metamorphic series which stretches all across Scotland from Aberdeenshire to Kintyre, and almost everywhere the excessive crumpling of the foliation planes and the abundance of quartz in strings and veins are common phenomena, so that these are not due to the intrusion of the granite, as many of the earlier writers supposed. The rocks are similar in character to those which occur in Bute and Argyle on one side, and in Kintyre on the other, in districts where there is no granite intrusion. They are generally called slates by previous writers, but slates form only a part of the series of rocks, many of them being coarse and gritty schists or schistose pebbly grauwackes. The foliation planes must not be taken everywhere for the bedding, as sometimes there is a considerable discordance between the two.

The ring of schists is incomplete on the east side of the island for nearly three miles. There is none from Glen Sannox to the White Water, and in Glen Rosie the band is narrower than generally represented, being less than 700 yards in breadth.

Old Red Sandstone.—A very long period elapsed between the schists and the formation of the Old Red Sandstone, which in one or two places may be seen resting unconformably on the

[1] No attempt has been here made to describe completely the geology of Arran, only broad views of the general structure and the relations of the formations to one another are stated, new points are noted, and old mistakes corrected. Details will be given in the memoir to be published when the island is completely surveyed.

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older rocks, but nearly everywhere is faulted against them. The Old Red Sandstone extends along the east side of the island from Laggantuin to Brodick Bay in a band of varying width, which is very much faulted; and from Brodick Bay westwards in a broader band, which extends as far south as the Clachan Glen, more than three miles south of the String Road. Here it is greatly invaded by masses of granite, granophyre, quartz porphyry, diorite, and gabbro, rocks probably of Tertiary age, by which all the surrounding strata have been highly altered.

About North Glen Sannox there are three distinct divisions in the formation. The oldest is a group of typical lower conglomerates, purple mudstones, and felspathic sandstones, the stones in the conglomerates being large and well-rounded, and consisting mainly of pinkish quartzite. Next comes a thick group of pale-coloured or whitish quartzose conglomerates and sandstones in which the pebbles are not so large, and consist mainly of quartz. This series is probably unconformable on the lower one. There is an upper group of red sandstones and conglomerates made up largely of débris of the lower division and of the schists. It is this upper Old Red group that appears along the east coast of the island. Between this and the middle group a set of contemporaneous red lavas and tuffs of a basic character intervenes, which had not previously been noticed in the island.

The upper Old Red Sandstone which appears on the coast north of Corrie as far as the Fallen Rocks, and which has been taken as the general type of the Old Red Sandstone of the island, forms only a small part of the formation, and is little seen in the interior, while the lower division scarcely appears on the coast except on the west side south of Dougrie, and there only one type of it is found. In Glen Shirrag there is a great thickness of red and purplish-red or chocolate micaceous sandstone, often hard and thin bedded, which forms the highest portion of the Lower division, and is perhaps 2000-3000 feet thick. Everywhere here the dip is high and often vertical, generally towards east or E.S.E., but in several places, as in the Cnocan Burn and south of Glen Rosie, the dip is reversed, and as the beds do not seem to be rolling or contorted, they must be inverted. It was in these beds that Psilophyton was found in 1872 by one of Sir A. Geikie's class, the only fossil as yet that the Old Red Sandstone of Arran has yielded.[1] There seems little trace in Glen Shirrag of either the Upper or Middle groups of the Old Red Sandstone, and their absence seems to be due to overlap of the Carboniferous Rocks. North of Corrie the Upper group seems unconformable on the Middle, or on the Lower group where the

[1] Other specimens have been collected since the paper was written.

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Middle one disappears. The thick masses of mudstone interstratified with conglomerates, that form so large a portion of the formation in Glen Sannox, only appear in Glen Shirrag in an attenuated form.

In Glen Rosie, faulted against the schists, is a type of the rock which is not red but grey in colour, and otherwise of a different character, containing a different set of pebbles. Beds of this type may be seen in the Rosie Burn at the bend of the stream 700 yards south-east of the foot of the Garbh Allt. They are vertical, strike N.N.E., and seem to have hitherto been confounded with the schists.

Carboniferous Formation.—The Carboniferous Rocks of Arran, where developed most fully, as at Corrie and S. of the Cock, embrace representatives of the various strata from the Cementstone base up to about the horizon of the Millstone Grit. As there is a good deal of misconception as to the position and importance of these rocks in Arran, it may be as well to describe their distribution in some detail. They really form but a very small portion of the island. On the north-east coast a narrow strip of them, 3 miles long, occurs between the Cock and the Fallen Rocks, the thickness of which has been much exaggerated, because no account has been taken of numerous faults repeating the beds. There is also a narrow band of Carboniferous Rock —200 yards wide—between two faults on the north shore at the mouth of the burn east of North Newton. At Corrie these rocks stretch along the shore for two-thirds of a mile, with an average dip of 20° to 25°—making a total thickness of 1200-1500 feet, inclusive of a thick band of contemporaneous trap 300 to 400 feet thick, often called a dyke.[1] Several of the Upper Limestones are visible at Corrie on the horizon of the Edge coals. Inland these beds are cut off by various faults which shift their outcrop southward, and one of these shifts them more than half a mile, and has a throw-down east greater than the thickness of the whole series. North of Maol Donn (which is Newer Red Sandstone) the breadth of the Carboniferous band is less than half a mile. A fault runs along the west side of the hill which throws out all the Carboniferous rocks except the lowest, the Volcanic series. We get the Carboniferous beds again in the Clachland Burn, and they can be traced S.W. through the wood and behind Brodick Castle in a steeply dipping band altogether 200 to 300 yards in width. Some of the beds are seen in the Rosie Burn at and above the bridge, and the white thick sandstones are a conspicuous feature about Brodick Church, at the back of which the thick Corrie Limestone was formerly worked.

[1] The beds are covered unconformably by the Newer Red Rocks 250 yards south of the Corrie Hotel.

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A large fault west of this throws the beds up to the hill side southward, whence they can be traced to the S.W. in a steeply dipping narrow band 200 yards in width. As we proceed the upper beds of the series are successively but gradually being overlapped by the Newer Red Sandstone, which forms a conspicuous feature above them to the S.E. Some of the beds of the Carboniferous are entangled in the intrusive mass of the Windmill Hill, almost dividing it into two, and here the beds are probably inverted. Owing to intrusive masses and to faults the Carboniferous rocks are shifted S.E. for more than a mile to the south side of Glen Dubh, and can thence be traced in a broken way southwards to Benlister Glen, where the Newer Red Rocks rest on the Corrie Limestone, and onwards to Cnoc-a-Chapuill, where the limestone has disappeared, and only the Volcanic series remains. Still farther westward even this disappears, and the Carboniferous Formation is entirely gone, not reaching to the west side of the island.

Another and thinner Carboniferous Volcanic series, on the horizon of the Upper Limestones, has been found in the Clachland Burn, and in the woods to the S.W. It is 10 to 25 feet thick—a red series of lava and tuffs very like the lower and thicker mass.

Newer Red Rocks.—There has hitherto been considerable difference of opinion as to the age of the red rocks south of the road leading from Brodick Bay to the west side of the island, various writers describing them either as New Red, Carboniferous, or even Old Red Sandstone, and one—Ramsay—as partly New Red and partly Carboniferous. A mass of red sandstone and conglomerate occurring near the Cock in the N.E. of the island was generally regarded as New Red also, and here, many years ago, Mr James Thompson found in the conglomerate at the base of this series derived pebbles of Carboniferous limestone, with its characteristic fossils, a discovery fully confirmed by the Geological Survey in 1894. The corresponding break on the south side of the anticline occurs about 250 yards south of the Corrie Hotel, where the Upper Carboniferous limestones and shales are covered by a thick series of false-bedded red sandstones, which occupy the shore between Corrie and Brodick, and form the fine hill of Maol Donn. This point was determined in the spring of 1894 by Sir A. Geikie, Mr Peach, and myself. In both localities the two formations seem almost conformable, but when traced inland the upper one is found to be decidedly unconformable to the lower, and gradually overlaps it till the Carboniferous Rocks entirely disappear before reaching the west side of the island. South of Corrie these Newer Red Sandstones and conglomerates repose on the uppermost members of the

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limestone series or the base of the Millstone Grit. In the interior, near the head of Benlister Glen, they lie on the Corrie limestone, hundreds of feet lower down in the Carboniferous system, while on the west coast north of the Machrie Water they appear to come down upon the Old Red Sandstone, the whole of the Carboniferous formations having there disappeared.

These upper unconformable and overlapping red strata may be divided into two fairly well-marked sections—a lower group, consisting of massive and flaggy sandstones with conglomerates, varying from a bright brick red colour to tints of yellow or grey, and an upper group of red marls and shales, containing thin sandstones and occasional thin bands of nodular limestone. The upper division extends through all the southern and a part of the western district of Arran, from Dippin round to beyond Drumadoon. No decisive evidence has yet been obtained to fix the exact geological age of this Newer Red series of strata.

These Arran red sandstones, however, enclose a contemporaneous Volcanic group very similar to one in the Permian rocks of central Ayrshire, and also occurring in Nithsdale. At the head of the Sliddery Water is found a group of dull-red slaggy lavas and red tuffs, apparently intercalated among the Newer Red Sandstones. The tuffs seem to greatly preponderate, are nearly all red or purple, and vary from fine muds to coarse agglomerates. They include two bands of sandstone and shale, among the fallen débris of which a large and fine specimen of Stigmaria was found; and other fossils will probably reward further search. Mr Kidston, to whom this plant was referred, believes it to be either Carboniferous or Permian. (1894.) In 1895 I obtained additional, though somewhat doubtful, plant remains, apparently from sandstones that overlie the newer Volcanic group. But, unfortunately, these volcanic rocks are so nearly surrounded by intrusive igneous masses that their relation to the surrounding sandstones is not free from doubt.

However, as helping to support the view that these tuffs and lavas belong to the Newer Red Series, and are not the Lower Carboniferous tuffs brought up in some inexplicable way, we have the fact that on the south side of Brodick Bay, in the Newer Red Conglomerates, there are found two volcanic necks filled in with an irregularly arranged and cemented agglomerate. It is true there is no igneous material in the mass, but volcanic necks, composed entirely of fragments of clastic rocks, are not unknown elsewhere.

It will thus be seen that, including this group of Sliddery Water head, there are no less than four sets of contemporaneous volcanic rocks in Arran—one in the Old Red Formation, two in the Carboniferous, and one in the Newer Red Rocks.[1]

[1] There is, perhaps, still another in the Lower Old Red Formation.

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As very shortly a thorough search for fossils is going to be made in these Newer Rocks, it is to be hoped that something will turn up to enable us to fix definitely their age. Meanwhile, they are provisionally regarded as Permian.

Intrusive Igneous Rocks.

The number and variety of intrusive masses and dykes over a great part of the Island of Arran are perfectly bewildering. They belong to three great groups—basic, intermediate, and acid. Among the basic are dolerite and diabase (several varieties), basalt, and gabbro.

Intermediate kinds are diorite and quartz diorite, trachyte and others. The acid rocks include felsite and quartz porphyry (three varieties), pitchstone, granophyre, microgranite or porphyrite, and two varieties (at least) of granite.

The finer grained felsite sheets are very generally distributed over the southern part of the island. They are often spherulitic, and may in some cases be devitrified glassy rocks. The coarse grained, peculiar quartz porphyry, with rounded crystals, occurs in three distinct areas—Drumadoon, Brown Head and Kilmory Water. The latter connects with the Benan Head mass. In the lower part of the Sliddery Water, a somewhat intermediate kind of quartz felsite occurs. The fine-grained felsite is newer than the coarse quartz porphyry, into which it is intruded in the form of dykes and sills. Accompanying the quartz porphyry of Drumadoon and Benan there is a mass of basic rock, which forms a kind of fringe or selvage to it, sometimes with what appears to be a rock of intermediate character between them. Field evidence is strongly in favour of these acid and basic rocks of Benan being practically of one age and not separate intrusions, and microscopic evidence, according to Mr Corstorphine, confirms this view.

A great many small acid intrusions as sills and bosses are found in the interior of the southern part of the island, as also many felsite and quartz felsite dykes, but, strange to say, very few of such appear on the coast. There is only one felsite dyke of any importance along the whole southern coast, while the number of basalt dykes there is legion. The felsite dyke occurs east of Torrylin, and is 30 to 40 yards broad, with a basalt dyke in it near the centre.

The numerous basalt and dolerite dykes for which the south end of Arran has long been celebrated have a general northerly trend, and appear to be all of the same age or nearly so. They undoubtedly cut through the quartz porphyries and the coarse-

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grained basic sills, but are less numerously visible in the finer-grained basic sills, while in the felsite sheets they are seldom to be seen. In several places dykes running in an east-north-east direction cut the others, and are therefore of later date, but all are presumably of the Tertiary period.

Pitchstone, for which Arran has long been noted, occurs in a good many places in the form both of sills and of dykes, but in both forms it is more irregular than any of the other igneous rocks, and none of the outcrops can be traced very far. There seems to be a good deal to favour the view that pitchstone passes horizontally into spherulitic felsite.

The boundary of the great granite mass has been traced from near Loch Ranza round its eastern and southern border to Glen Iorsa. On the whole, the line is a very even curve, with no marked projections of importance—only very small ones. The granite is intruded everywhere into the schists except for about three miles along its eastern border, where it comes in contact with the Lower Old Red Rocks. The alteration of the surrounding rocks is comparatively little in places; most intense in Glen Rosie, where it can be noticed 300 yards from the edge; and east of Ciochna h-Oighe. The alteration is comparatively slight at the White Water, and can scarcely be noticed 20 or 30 yards from the granite edge, the Lower Old Red Sandstone retaining its colour and bedding quite distinctly, and only near the junction is the rock changed from purple to grey, and hardened and splintery. The coarse-grained whitish granite of the margin which forms all the big peaks weathers with a very rough surface generally, and contains mica sparingly, except locally, where black mica is pretty abundant. Basalt dykes, though small, are pretty numerous in it, and to the weathering of these and other dykes, as of quartz felsite and pitchstone, is due in a great measure the serrated character of the ridges and the peaky outlines. In places there are pretty numerous dykes and sheets of a finer granite, and occasionally this occurs in patches which seem to be segregations and not intrusions. There are numerous joints often dipping at comparatively low angles, which give to the rock an appearance of being bedded. These are very striking in places. Records are kept of the dip, etc., of these to see if any light can be thrown on their origin. The granite is certainly of later date than the Old Red Sandstone, which it alters, and also later than faults which affect that formation, continuations of which faults also affect the Carboniferous Rocks. Numerous faults about Maol Donn, which affect the Newer Red Rocks, seem not to penetrate the granite, though some of them might have been expected to do so if the granite were the earlier rock, and there are no derived fragments of the granite

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in any of the surrounding formations. Crushes and faults in it are not so numerous as one would expect in a very old rock, and the dykes are similar to those in the Newer Red strata, with the exception of those of fine-grained granite. Everything, therefore, points to a comparatively recent date for its origin.

South of the String Road occurs the intrusive complex referred to in the section on the Old Red Sandstone. It is of an oval form, about 4 miles by 3, and has yet been but partly mapped. Sufficient is known of it, however, to make it one of the most interesting parts of the island. Granophyre, passing into granite, occupies the south side of Gleaun an't Suidhe, near the String Road, and all the highest ground south of it, from Cnoc Dubh by A'Chruach and Beinn Bhreac, round to beyond Ballymichael Glen; is continued along the east side of Ard Bheinn, and takes up a great part of Glen Craigag. The so-called Ploverfield granite is a part of this area. A smaller area runs westwards from Glenloig, which includes the Creag Dhubh granite of Bryce. The rock varies a good deal towards a rather course binary granite, with little mica on one side; and on the other (by losing much of the quartz and becoming rich in hornblende) it becomes the syenite of old authors. Also, near the edge, it sometimes passes into a rock that may be called either a felsite or quartz porphyry. There seems no sharp line between the different varieties, and there are several other places besides the two mentioned where the rock may be called a granite. One small area of this kind, quite detached from the rest, lies a little north of Dereneneach, close to the road, and is low ground.

At the head of Glen Dubh (upper part of Glen Cloy) there is a mass of diorite about one mile long by half a mile broad, and there are some others about the rugged hill of Ard Bheinn, where a quartz diorite was noticed and described by Prof. Zirkel twenty-five years ago. There is clear evidence that the diorite is older than the granophyre and granite, as it is penetrated by these in veins and sills. Now the diorite of Glen Dubh must be of later date than the Newer Red Rocks, as it alters them, and the granophyre, being intrusive in the diorite is of still later date.

To the east of Glenloig are found three or four masses of gabbro, one of which forms Creag nam Mult, and here the basic rock is penetrated by a granophyric mass, just as are the gabbros of Skye. From the resemblance these rocks bear to those of Skye, and from the fact that they are newer than all the sedimentary rocks of the island, it seems fair to infer they are of the same age as those of Skye—viz., Tertiary.[1] Both acid and basic rocks are pierced by the ordinary basalt dykes.

[1] A similar train of reasoning favours the view that the main mass of granite in the north of the island is Tertiary also.

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Of other intrusive masses, the Windmill Hill quartz felsite is perhaps the best known. It is generally a fine-grained grey rock with small free quartzes, and only here and there is more largely porphyritic. It does not seem to be pierced by any dykes of quartz porphyry, though there are several coarsely porphyritic dykes seen in the stream below, which might be expected to appear in it, and it would therefore seem not to be of earlier date than these dykes. It is crossed, however, by several faults and crushes which are of older date than the basalt dykes which penetrate it. It is probable, notwithstanding, that all these intrusions belong to the Tertiary period, and also all the other intrusive rocks of the southern part of the island.

But there are one or two igneous masses which may be much older. A broad basic dyke 50 yards wide, ranging E.N.E. on the south side of Glen Sannox, is confined to the Lower Old Red Formation. It is shifted a long distance by one of the north and south faults, and though traceable for half a mile, does not seem to penetrate the granite on one side or the Upper Old Red Rocks on the other. In Glen Rosie, on the south side, is an intrusive rock, apparently of an intermediate type, which occurs as a sill in the Old Red Sandstone. It can be followed S.W. for about a mile, with an average breadth of 100 yards, forming the hills Torr Breac and Torr Dubh. The adjoining rocks in the Rosie Burn are much altered. It is a brown or grey rock, often fine-grained in character.

In Cnocan Burn, just below the old mill dam, is found a section which has an important bearing on the age of the granite mass. It seems to have been first described by Bryce. A basalt dyke is penetrated by a vein presumably an injection from the granite, the boundary of which is not far off; and if this is one of the ordinary basalt dykes of Tertiary age, and the acid vein is an offshoot of the granite, the Tertiary age of the granite is determined.

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XLI.—*The Greensand Fossils from Drift-Beds at Moreseat, Cruden, E. Aberdeenshire, with Exhibition of Specimens Collected.* By DAVID J. MITCHELL, Schoolhouse, Burnhaven, Peterhead.

(Read 15th April 1897.)

THE estate of Moreseat is situated in the parish of Cruden, in the district of Buchan, East Aberdeenshire. It is about 500 feet above sea-level, and five miles west of Buchan Ness.

The existence of the Greensand deposit there was known in the early part of the present century. Dr Ferguson of Kinmundy says: "The fact of its existence was first communicated by the late Dr Knight of Marischal College, Aberdeen, to the late Dr Thomson of Glasgow College." The late lamented Hugh Miller, in his "Sketch-book of Geology," page 113, also mentions the Greensand formation.

It is part of an extensive Cretaceous deposit in Cruden and in the adjoining parish of Slains.

The deposit in Slains, which was examined by Dr Jamieson, Waterton, Ellon, has, on the authority of Mr Searles Wood, been relegated to the "Crag."

The Greensand formation was more fully brought to light under the following circumstances. The late Mr Johnstone, proprietor of Moreseat, made an excavation at his farm-steading for the purpose of putting in a water-wheel to drive a new thrashing-mill.

In the material excavated, pieces of fine light-coloured sandstone (a most uncommon rock in the district) were found. These sandstone fragments, on closer examination, revealed the presence in them of fossil-shells.

This deposit was examined by the late Dr Longmuir, Aberdeen, who wrote a paper on the subject.

The Greensand rock has been aptly described as consisting of "Calcareous sand, visibly stratified, of grayish hue and containing comminuted shells."

One of the fossil specimens got in the rock from the water-wheel excavation was the cast of a large Ammonite. The Greensand bed was found about 9 feet below the surface of the soil. Dr Ferguson of Kinmundy knew of the Greensand at Moreseat, through having noted its existence while attending lectures at college. Before he began his investigations, the bed

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above mentioned was beyond reach, as the water-wheel had been put in and the hole filled up. The spare excavated material was utilised for the purpose of top-dressing and levelling some of the fields on the farm.

Dr Ferguson found the most of his specimens in a ditch, while it was being made for the purpose of fencing a newly reclaimed field. This ditch was about 400 yards north-east from the farm-steading. He examined it about the year 1850. He got the Greensand beds at about from 1 to 3 feet below the surface. The deposit extended for fully 100 yards. He had an excavation of about 7 feet deep made. The section of this, as described by Dr Ferguson,[1] "presented irregular layers of unctuous clay of a dark-brown colour and soapy feel, and so tough and adhesive as to render it a work of considerable difficulty to dig it out. Interstratified with this clay were thin layers of a compact sandstone. These layers of sandstone were not continuous. They graduated into each other, thinned out, disappeared, and reappeared most confusedly. They were very much inclined, dipping towards the south. The whole mass had the appearance of having been drifted, although from the nature of the matrix and the state of preservation in which the shells were found, it does not appear as if it could have been transported far. The sandstone is tough and soft when newly dug, but hardens on exposure to the air, and becomes light-coloured in drying. When wet it presents a mottled appearance, the colour being greenish; when dry this almost disappears. The exterior surfaces were often quite reddened with iron. Many of the remains are casts and are on the outer surface of the fragments of sandstone, as well as in the interior of the masses. Of the remains themselves flattened spatangi are most abundant." Dr Ferguson sent his collection of specimens to Jermyn Street for examination, and the best of them are at present in the Museum of Practical Geology.

The experts, Messrs Salter and Baily, examined and identified the specimens. Their opinion was that the species represented, indicated the rock was of the Upper Greensand Age, and that it was a drifted deposit.

Some of the species were new. One was named *Cyprina Fergusoni*, in honour of the finder, Dr Ferguson. Mr Salter wrote a paper on the fossils, describing them and giving reasons for his conclusions. It appeared in the Quarterly Journal of the Geological Society, vol. xiii.

He based his conclusions as to the age of the rock (viz., Upper Greensand) on the occurrence in it of such fossils as

[1] Paper by Dr Ferguson on "Chalk-flints and Greensand," vol. iii. pt. 2, Transactions of Buchan Field Club.

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Galerites castanea, Arca carinata, Pinna tetragona, and especially of *Thetis major.*

He regarded the discovery as most important and further said: "There are many points of interest connected with the former extension of Cretaceous rocks from Sweden over the northern part of Britain which must receive illustration by the recording of such facts as those." In a note appended to Mr Salter's paper Dr Ferguson gives it as his impression that the deposit is not *in situ* but drifted, but that it could not have come far.

Mr Salter questions the possibility of the soft sandstone withstanding drifting, had it been from any of the known similar deposits in England (the farthest north of these being in Cambridgeshire). He thinks rather that it must have come from some place in the vicinity of its present situation. About two years ago Dr Ferguson, in his retiring address as president of the Buchan Field Club, described his experiences and work. Thereafter I visited Moreseat with some other gentlemen in quest of the interesting deposit. My interest in it was aroused when, in a concluding paragraph of his paper, Dr Ferguson said: "I am not aware that any new facts have been elicited as regards the topics (Chalk and Greensand) which have been our subject to-night, and I feel that the question altogether is one involved in considerable darkness, and that it is vain to attempt generalisation upon it, till the local geology has been far more accurately examined and determined. It is a matter well worth the while of the members of your club to investigate."

The deposit had been practically untouched since Dr Ferguson had worked at it.

All the excavations previously made, from which specimens had been got, were unavailable, as they had been filled up.

The first find was a small fragment of Greensand, which was picked up on the edge of a ditch, about 400 yards north-west of the farm-steading, and about 500 feet above sea-level. The ditch had been previously cleaned, and the Greensand thrown out. Having been left for a considerable time exposed to the influence of the atmosphere it was quite dry and brittle, and broke quite easily. In it was found a small bivalve fossil.

A little to the north, and at a greater elevation, an extensive deposit of fine sand similar to that found commonly on the seashore, is to be seen. This is most likely an old sea-beach.

Where the Greensand was picked up an excavation was made in the bottom of the ditch, which here was about 3 feet deep.

The same order of things as described by Dr Ferguson was discovered. There was the same dark brown soapy clay. Mixed up with this clay were numerous nodules of Greensand, appar-

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ently drifted, as they were much worn and rounded. The pieces of rock found, were carefully broken and examined for fossil remains with some success.

Enough was seen to justify a speedy return visit for farther examination and discovery.

This excavation was frequently revisited, enlarged, and deepened. It proved to be the most important of the several sinkings made, both as regards the quantity of Greensand and its richness in fossils.

The section presented various aspects. Near the top there were the much worn and rounded pieces of Greensand mixed with the clay. These soon disappeared, giving place to layers of the rock, which at first appeared to be solid masses separated by clay. The layers, however, on examination, were found to be in a very shattered condition, which only became apparent when they were handled. They were at various angles, but the general dip was towards south-east. They all gradually thinned out and disappeared. The presence of pebbles of quartzite and granite was noticed for some time, but at the lower part of the excavation they had disappeared, although the Greensand layers and the clay continued right to the bottom. The depth reached would be about 9 feet below the surface of the surrounding fields. The lowest shattered layers were extremely rich in fossils. It was necessary to exercise considerable care in removing the broken pieces from the layers, as very often casts of shells and spatangi were got between the fragments, lying quite loosely. These undoubtedly would have been lost if a spade had been roughly or carelessly used. Instead, the clay surrounding the layers was removed with an old knife, and the pieces of rock and fossils carefully laid aside. Some of the best fossils found were lying loosely between the shattered fragments. In fact, the lines of fracture in the rock generally occurred where there were fossils. The excavated rock was next washed to get rid of the adhesive clay. It was then allowed to dry for some time, and was in consequence more easily broken for minute inspection. Each bit of any size was split carefully and examined for fossils. The results were sometimes very discouraging. The largest pieces were not always most productive of specimens, and contiguous masses were often very dissimilar in their yield of fossils. Generally the rock was easy to manipulate, being soft and fragile while wet, and free and crumbly when dried.

About twenty yards farther north up the same ditch another hole was dug, which yielded similar results. The digging here was a work of considerable difficulty, and the place was in consequence abandoned.

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Some fragments of Greensand were one day picked up on the edge of another ditch, alongside the accommodation road which runs westward over the farm. This spot was south-east of the first excavation. A hole was dug in the bottom of the ditch. Here the Greensand had every appearance of solid rock, but like that in the first excavation it was much shattered, although the fragments in this case were considerably larger. The rock layers dipped at an angle of 30° under the road, whither they could not be followed. The yield of fossils was poor. Most of the pieces of rock were almost destitute of remains, and were harder and closer-grained than in the former pits. The large masses were quite angular, shewing few signs of tear and wear from drifting, and apparently they could not have been carried far.

Several other holes were dug at random in the fields north of the mill-pond on the farm, and numerous specimens of the rock were met with, generally at no great depth under the surface, showing the deposit extends over a considerable area. Many pieces were got along the sides of other ditches in the fields.

The last important excavation from which some of these specimens were obtained, was in the bottom of the mill-pond. Here a hole about 5 feet square and 4½ feet deep was formed. A yellowish clay of a most tenacious character was first encountered. It was exceedingly difficult to dig. Under it the dark-brown greasy-looking clay already referred to was again met with. The Greensand pieces got here were, in the upper part of the section, quite red with rust, and in the lower part of it, quite black. When washed and dried, they were found to be as hard as iron, and hardly breakable. Worst of all, they were poor in their yield of fossils.

These several excavations were the result of oft-repeated visits and much toilsome digging.

A thorough examination of the surface of the higher grounds to the N., N.W., and W. went to show that no Greensand fragments were visible in these quarters as there were farther to the south.

The rock examined by me yielded fully 400 specimens of fossil remains, in the form of casts or impressions. That examined by Mr Insch, of Peterhead, produced similar results.

My collection of fossils was first submitted to Professor Nicholson, of Aberdeen University, with a view to their identification. He advised me to have them examined by an expert in Mesozoic Palæontology. Through the kind offices of Dr Milne, King Edward, and of Professor Judd, my collection and that of Mr Insch, Peterhead, were, with the consent of Sir

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Archibald Geikie, examined by Messrs Sharman and Newton, experts in the Museum of Practical Geology, Jermyn Street, London. The result of their painstaking labour has been embodied in a most interesting note, which was published in the Geological Magazine, in June last year.

Their conclusions are most gratifying to the recent investigators, in so much that they indicate that our labour has been not altogether in vain.

As has already been mentioned, Mr Salter concluded from what he found in Dr Ferguson's collection that the deposit therein represented was a rock of Upper Greensand Age.

Messrs Sharman and Newton say: "The specimens sent are all in the condition of internal and external moulds, in a light-coloured, fine-grained sandstone, and although slight differences may be noticed in different pieces of the rock, they are all so similar that one can scarcely question their having been originally derived from the same bed. Notwithstanding this, the fossils clearly indicate *more than one horizon.*"

They next notice the similarity of the recent specimens to those of Dr Ferguson in the Museum of Practical Geology in London.

After a scientific description of the fossils, in the concluding paragraph of their paper, they say: "While the *Echinocyphus difficilis, Micrabacia coronula, Galerites castanea,* and *Pectunculus umbonatus,* indicate an Upper Greensand fauna, the *Ammonites Crioceras, Trochus pulcherrimus, Astarte-striato-costata, Trigonia vectiana, Cardium Raulinianum, Arca Raulini, Plicata placunea,* and *Lima Dupiniana,* point even more strongly to a Lower Greensand Age."

"It would seem, therefore, that the faunas which in the South mark the distinct horizons of Lower Greensand, Gault, and Upper Greensand are, here in Aberdeenshire, included in one bed of nearly uniform character throughout. However that may prove to be, it is clear that these Drift Specimens have been derived from beds where a large part of the Cretaceous series of strata occurs, not only Upper and Lower Chalk, and Upper Greensand, as pointed out by Salter, but also beds of Lower Greensand or Speeton Clay Age."

"What relation these beds may have to the Lower Cretaceous of Sweden, or to the Neocomians of Heligoland and North Germany, which are now occupying the attention of Dr Danes and Professor von Könen, it will be of interest to know; but this must await future investigation."

By these recently identified fossils the district of Buchan is now proved to possess a more complete series of Cretaceous horizons than was formerly known to be the case.

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The work of investigation is still going on, and we are hopeful that ere long, with more complete information, a satisfactory solution of this most interesting geological problem will be arrived at.

Two years ago the British Association gave a grant of £10 to a committee, consisting of Dr Jamieson, Ellon (chairman); Mr A. Jukes Brown, London; and Dr Milne, King Edward (secretary), to help to determine the age of certain rocks belonging to the Cretaceous age at Moreseat, Aberdeenshire.

The work was delegated to Mr Tocher, secretary of the Buchan Field Club, and myself. In the spring of last year the money was expended in sinking a shaft 6 feet in diameter through the deposit. The depth of the excavation is 30 feet, and it is slightly to the north of our first excavation in the ditch and at a higher elevation.

It was hoped that the rock might be found *in situ*, but the result has been quite otherwise.

The shaft passes through clay all the way down. Greensand fragments and then layers are abundant near the top, but gradually get fewer and finally disappear altogether as the excavation increases in depth.

The fossils found in the Greensand from this excavation are in the hands of Mr A. Jukes Brown, who has not yet reported on them, but doubtless something interesting will result.

The full report of the work of the committee as carried out by us will be read at the next meeting of the British Association.

The excavation, I think, seems to prove that the Moreseat Greensand deposit is a drift and not rock *in situ*.

If that be so, how came these beds, and whence?

I am afraid that we can only theorise on that question.

Various ideas strike one. The bed might be the result of drift from some deposit in the vicinity, but no such formation is known to exist.

It might have been drifted from the basin of the Moray Firth, the western and southern shores of which shew evidence of an older series of rocks than Greensand. There are evidences in drift rocks at and around Moreseat that the ice-drift passed thither from the Moray Firth districts.

There is a great probability that the western drift of ice over Northern Europe brought the deposit in question with it from beds (cretaceous) *in situ* somewhere out in the North Sea, towards the east of Moreseat. These beds (?) might be a prolongation towards the west of the Cretaceous series in Scandinavia and Western Europe. That this theory is the correct one might be proved from the fact of the existence of the Crag

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deposit in Slains, which is farther to the south than Moreseat, and more distant from the Moray Firth basin.

It is hoped that the Fellows of the Edinburgh Geological Society may be able to prove to their satisfaction which of the hypotheses advanced is the correct explanation of the presence here, in Aberdeenshire, a district where granite is the prevailing rock, of the interesting Cretaceous drift deposit which has been the subject of this paper.

The following list of fossils found at Moreseat was compiled by Messrs Sharman and Newton, and appears in their paper in the Geological Magazine of June last, which see for the scientific description of the fossils.

MESSRS SHARMAN AND NEWTON'S LIST OF FOSSILS (CRETACEOUS) FROM MORESEAT, ABERDEEN, SHOWING RANGE OF THE SPECIES.

Mitchell Collection.	Insch Collection.	Ferguson Collection.		Lower Greensand, Speeton Clay, etc.	Gault.	Upper Greensand.	Chalk.
			Cœlenterata.				
		F.	Micrabacia coronula, Goldf.	—	—	×	×
			Echinodermata.				
		F.	Ananchytes (Holaster),	—	—	—	—
		F.	Diadema,	—	—	—	—
		F.	Discoidea,	—	—	—	—
		F.	Galerites (Echinoconus) castanea, Brong.	—	—	×	×
M.		F.	Enallister (Toxaster) Scoticus, Salt,	—	—	—	—
M.			Echinocyphus difficilis, Ag.	—	—	×	×
			Annelida.				
	I.		Serpula,	—	—	—	—
			Polyzoa.				
	I.		Entalophora?	—	—	—	—
			Brachiopoda.				
		F.	Rhynchonella compressa, Lam. (?dimidiata),	—	—	×	—
M.	I.		Rhynchonella sulcata, Park,	×	×	×	—
M.	I.		Terebratula,	—	—	—	—
M.	I.		Waldheimia hippopus, *var* Tilbyensis, Dav.,	×	—	—	—
			Lamellibranchiata.				
M.			Arca Raulini? D'Orb.,	×	?	—	—
M.	I.	F.	Astarte (Venus) Striato-costata, Forbes,	×	—	—	—
M.	I.	F.	Avicula Simulata, Baily,	—	—	—	—
M.			Crasatella (probably),	—	—	—	—
M.			Cardium Raulinianum, D'Orb.,	×	×	—	—
M.			Corbula,	—	—	—	—
M.	I.	F.	Cucullæa carinata, Sow.,	—	×	×	—
M.	I.	F.	Cyprina Fergusoni, Salt,	—	—	—	—
M.	I.		Exogyra?	—	—	—	—

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MESSRS SHARMAN AND NEWTON'S LIST OF FOSSILS—*continued*.

Mitchell Collection.	Insch Collection.	Ferguson Collection.		Lower Greensand, Speeton Clay, etc.	Gault.	Upper Greensand.	Chalk.
			Lamellibranchiata—(continued).				
M.			Gervillia (near to rostrata ?)	—	—	—	—
M.			,, solenoides, Defr.,	×	×	×	—
M.	I.		Goniomya, sp.,	—	—	—	—
M.	I.		Inoceramus,	—	—	—	—
M.			Lima Dupiniana, D'Orb.,	×	—	—	—
		F.	,, semisculata, Sow.,	—	—	×	—
M.	I.		,, (near to abrupta),	—	—	—	—
M.		F.	Limopsis texturata, Salt.,	—	—	—	—
M.	I.		Lucina ? sp.,	—	—	—	—
M.			Nucula,	—	—	—	—
M.			Ostrea ?	—	—	—	—
	I.		Panopœa,	—	—	—	—
M.			Pecten orbicularis, Sow.,	×	×	×	×
		F.	,, (probably the P. corneus of Nils, not of Sow.),	—	—	—	—
		F.	Pectunculus umbonatus, Sow.,	—	—	×	—
M.		F.	Pinna tetragona, Sow.,	×	×	×	—
M.	I.		Plicatula placunea, Lam.,	×	×	—	—
M.	I.		Spondylus,	—	—	—	—
M.	I.		Trigonia vectiana, Lyc.,	×	—	—	—
			Gasteropoda.				
M.			Actæon,	—	—	—	—
	I.		Cerithium aculeatum, Forbes MS.,	×	—	—	—
	I.		Phasianella (near to eroyna), D'Orb.	—	—	—	—
M.	I.		Trochus (pulcherrimus), Phil.,	×	—	—	—
		F.	,, (small elongated form) [? pulcherrimus],	—	—	—	—
M.	I.		Trochus (conical species),	—	—	—	—
M.		F.	Dentalium cœlatum, Baily.,	—	—	—	—
			Cephalopoda.				
M.	I.		Ammonites Mortilleti, P. and De Lor.,	×	—	—	—
M.	I.		,, Speetonensis (*cf.* Payeri, Pav.)	×	—	—	—
		F.	,, Selliguinus, Brong. ?	—	—	—	—
	I.		Belemnites,	—	—	—	—
M.	I.		Crioceras Duvalii ?, Lev.	×	—	—	—

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XLII.—*Obituary Notice of* JAMES MELVIN, *F.S.A.Scot., formerly a Vice-President of the Society.* By RALPH RICHARDSON, F.R.S.E., F.S.A.Scot.

(Read 29th April 1897.)

IN complying with the Council's request that I should contribute an Obituary Notice of Mr Melvin, I undertake a task which I approach with all the sympathy, respect, and esteem felt for one whose acquaintance I prized, and with whom I worked happily in various fields. When I first knew Mr Melvin he was tenant of the farm of Bonnington Mains, near Ratho, Midlothian, and one of the leading agriculturists of Scotland. He was a Director of the Highland and Agricultural Society of Scotland, and afterwards President of the Scottish Chamber of Agriculture. He had been employed by one of the greatest land companies in the world, the New Zealand and Australian Land Company, Limited, to value and secure landed estate in Australasia, and he became one of its principal directors in Edinburgh. The name "Melvin of Bonnington" was a household word among Scottish agriculturists, and he was recognised as one of the foremost and best representatives of the farming interest in Scotland.

Mr Melvin was born at Ratho Mains, his father's farm, in 1817. Possessed of extraordinary energy and a penetrating intelligence, of a vigorous constitution and most agreeable manners, it is not surprising that he made his way in everything that he attempted. A great traveller, he invigorated Old World notions by an application to them of those obtained in the New. A fearless enquirer, he visited every scene of interest he could reach; and he once confessed to me, with a sigh, that he had missed by half an hour witnessing the great earthquake of Ischia in 1883. When we reflect that by that catastrophe four or five thousand persons lost their lives, we can only rejoice that our friend did not share the fate of Pliny the elder, who allowed scientific zeal to outrun common prudence.

Mr Melvin's contributions to the *Transactions* of our Society are remarkable, both for their importance and for the proof they furnish that a busy man can find time for anything. He was so accustomed to rapid thinking and acting that he accomplished with ease what would have been a burden to a rusty mind.

I find Mr Melvin's first contribution to our Society so far back as 20th February 1868, when he read a paper "On the

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Causes which seem to have led to the Extinction of the New Zealand Moa" (*Transactions*, vol. i. p. 150). Mr Melvin had returned, as he says, from "travelling over the hilly dales and through the bush of the middle island of New Zealand," and he had seen, "whilst riding along the banks of a stream, or where some cutting of the surface had been made by a rush of water, or for roads or water races," portions of bones of the Moa or *Dinornis* ("wonderful bird"), species of which attained 14 feet in height. The extinction of the Moa he attributes partly to great changes in the vegetable growths, partly to frequent fires, and partly to the reckless destruction of eggs and young and old birds by the Maoris.

Mr Melvin's next contribution was a paper read to our Society on 15th March 1877, "On the Nature and Origin of the Surface or Vegetable Soil, and its Influence on Geological Phenomena." In this paper (*Transactions*, vol. iii. p. 124) he mentioned that in 1638 Dr Lister asked the Royal Society of London to prepare a map of the soils of England, a task still unaccomplished. He pointed out, however, that in France this had been successfully attempted by M. Achille Delesse, Professor of Geology at the Normal School of Agriculture and Mines, Paris. Mr Melvin then carefully reviewed the soils of various countries, and the theories of Hutton and Playfair.

Fired by Mr Melvin's exposition, I visited Paris in 1877, and calling on Delesse, then Ingénieur en chef des Mines, he showed me his celebrated "Carte Agricole de la France," in which all France is mapped according to its agricultural value. As I then resided in, and knew well, the western district of Midlothian, I resolved to attempt to construct a similar agricultural map of that county, provided I could secure the assistance of some experienced Midlothian agriculturist like Mr Melvin, whom I frequently had the opportunity of seeing, as he was a vice-president and I was then hon. secretary of our society. With his usual urbanity Mr Melvin consented to aid me, and on its completion, with his co-operation, my Agricultural Map of the County of Edinburgh was published in 1878, with an Essay on the Geology, Agriculture, and Meteorology of Midlothian, dedicated to Professor Achille Delesse.

Mr Melvin's next contribution to our Society's *Transactions* (vol. iii. p. 326) is a paper "On the Evidence the Vegetable Soil supplies as to Geological Time," read 15th April 1880. He expresses his conviction, "from close observations of the surface coverings of the strata in this country and in several parts of Europe, as well as over different parts of Australia and New Zealand," that "these deposits have been the products of land ice." He considered it "impossible to account for the alluvial

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matter in which the gold in Australia and New Zealand is found, save through the action of moving ice." He concludes by advising geologists to "consider the evidence which the vegetable soil, loam, or mould affords as to the endurance of the present era;" and thus "gathered from all sources, evidence would accumulate which would eventually furnish sufficient data to approximate to the time it has taken to cover the earth's surface with loam."

I may conclude Mr Melvin's geologico-agricultural contributions to our Society by reference to his paper, read 5th May 1887, on "Hutton's Views of the Vegetable Soil or Mould and Vegetable and Animal Life" (*Transactions*, vol. v. p. 468), during the reading of which he presented to our Society's library the manuscript of James Hutton's unpublished "Treatise on Agriculture," of which Mr Melvin gives the gist in this paper. It was fitting that an eminent agriculturist should rescue from oblivion the work of one who had once been a practical agriculturist like himself, and whose thoughts were perhaps, like Mr Melvin's, first turned to geology by the daily observation of the soil during his agricultural operations.

Mr Melvin's two remaining contributions both deal with the subject of Parallel Roads. On 3rd December 1885 (*Transactions*, vol. v. p. 268) he read a paper "On the Parallel Roads of Lochaber," and on 16th February 1888 (*Transactions*, vol. v. p. 516) a paper "On the Parallel Roads or *Seter* of Norway." Regarding the renowned roads of Lochaber (of which Mr Melvin gives a map), he holds "that the roads have been traced on the mountain sides by the agency of ice and water," and that the only climatic change that has taken place in the locality since they were formed is an increase of the solar heat. He continues: "I therefore entirely agree with Professor Prestwich in his pamphlet on the roads (1879), 'that ice could not hold in water long enough to form them,' but disagree with him in believing that the hillsides slipped down when temporary lakes were drained, and that the water-run débris, which had given rise in his mind to the idea of general slips, was caused by summer melting of the snow on the hillsides washing down portions of the glacial stuff until it was caught by the ice at the level of the roads. Without the check the ice supplied, the rush of the débris would have continued to the bottom of the valleys, as in many places the incline is steeper below than above the level of the roads." Mr Melvin concluded "after careful consideration of the make-up of the terraces, the depth of the vegetable soil covering them, the hillsides, valleys, and the nature of the rock débris of the hillsides' stuff," that "no long period has elapsed since they were formed," and that the

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only reliable time-measurer, the depth of vegetable soil, does not indicate a period of many thousand years. Mr Melvin refers to terraces he examined in Otago, and remarks regarding the district of Lochaber, that it "has not its counterpart in Britain in its surface formation."

Three years later Mr Melvin gave our Society an account of his visit to the "Seter" or Parallel Roads near Hannestad, 177 miles from Christiania. He held that these Norwegian "Seter" strengthen the view taken by Professor Prestwich that 10,000 years or so was a great enough antiquity for them, and that ice had more to do with their formation than water.

These contributions by our late vice-president sufficiently prove the activity and independence of his mind, the zeal with which he pursued his researches, and the care he bestowed upon his facts.

During his early days Mr Melvin was an agricultural correspondent of the *Scotsman*. As I have mentioned, he held a high position as an agricultural authority, his experience, especially of farming in Midlothian, being necessarily great, for he was connected with Bonnington Mains during three nineteen-year leases. At one time he was spoken of as one who would make an excellent tenant-farmer candidate for the Parliamentary representation of Midlothian.

Latterly he resided in Edinburgh, where in 1868 he became partner of the firm of Alexander Melvin & Co., Boroughloch Brewery. His sterling character, his ripe knowledge, and his kindly disposition made him universally respected and beloved; and when he died at Edinburgh on 4th March 1897, in the eightieth year of his age, all felt that a man had passed away whose place would with difficulty be supplied.

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XLIII.—*A Hypersthene Andesite from Dumyat (Ochils).* By JOHN S. FLETT, M.A., B.Sc. Edin. (Plate XVII.)

(Read 29th April 1897.)

THE structure of the West End of the Ochils, where they terminate in the cliff overlooking Bridge of Allan and the Forth valley, is well exposed in many fine natural sections. Their extreme west end consists of massive beds of volcanic conglomerate, seen well in the narrow pathways behind Airthrey Castle. These are only irregularly bedded, and, while large blocks are few, they are, on the whole, coarse, and contain little fine detritus. The blocks have a rounded and distinctly water-worn appearance, and it is possible, every here and there, to find among them nests and patches of sand and shale, in a few places, amounting to distinct beds of sandstone. The general dip is to the N.W. about 10°.

The lavas are strikingly limited in development in the western area, while, as we ascend the slopes of Dumyat, they gradually become more and more important, and, finally, in very great measure replace the fragmental rocks. In the precipitous face of the hill overlooking Menstrie and Logie Church, every bed of lava and ash can be well seen, as they follow one another in regular succession. They form a regularly interbedded series, the lavas thinning out gradually as they pass westwards, while the ash beds close over them—a feature suggesting their origin from a volcanic focus situated to the eastward or south-eastward.

On the level moor, which forms the back of Dumyat, the sections are not quite so clear, but the structure is not difficult to read. The Sherriffmuir Road, which leaves the Forth Valley near Logie Church, and winds up over the higher ground, crosses the beds in a line roughly corresponding to their dip, and affords a series of sections in regular order of succession. The ash beds form little valleys, in which they are often overlaid by a thin coating of boulder clay which contains many rocks mostly carried from the districts to the north, while the lavas are sufficiently resistant to form outstanding cliffs which can be traced running down the hill. In these latter little quarries have been frequently opened to provide stones for road

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Fig. 1. (×25)

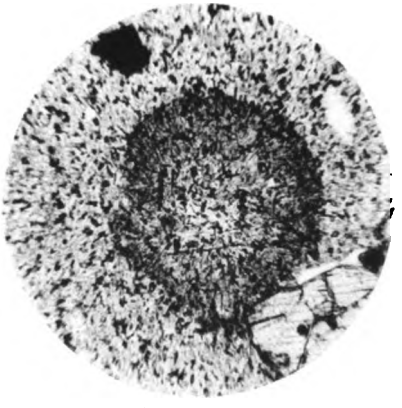

Fig. 2. (×24)

Hypersthene Andesite from Dumyat (Ochils).

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and dyke-mending, and these serve in some cases to clear up their relations to the ash beds with which they are mixed.

Fully a mile above Logie Church the dykes have largely been built of a very striking and beautiful rock. It is pitch-black in colour, with a velvety lustre and frequent veins of brilliant red. Its great freshness contrasts strongly with the weathered and dull-coloured porphyrites, of which the dykes are mostly composed. Examined carefully, it is free from vesicles, shows fairly well-marked fluxion structure, and consists of a felspar, with a green ferro-magnesian mineral in a ground mass largely glassy.

The microscope shows it to be a very typical and perfectly fresh Hypersthene-Andesite. The porphyritic crystals are Plagioclase felspar, Hypersthene, Augite, Magnetite, and Apatite. The ground mass is a brown glass, permeated by minute microlites, and may properly be designated hyalopilitic.

The felspars are plagioclase, and, according to the extinctions of their lamellæ, rank with Labradorite. They are often beautifully zonal, and show albite, carlsbad, and pericline twinning. Here and there an untwinned section occurs. Their sections are mostly elongated, and they have the usual form, the axis of elongation being the *a* axis, while they are often tabular on the brachypinakoid. In all cases they are corroded, even the most perfect having rounded corners, while the process may have gone so far that merely irregular grains and fragments remain. As a whole, they are very free from enclosures, but in some cases they are quite honeycombed with brown glass cavities. They are quite unweathered, and here and there they form glomero-porphyritic heaps with the pyroxenes and with magnetite.

Both monoclinic and orthorhombic pyroxenes occur, the latter in greater abundance. In ordinary light they are not easy to distinguish, both having a pale greenish-brown colour. But in polarised light the higher interference colours of the augite distinguish it at once, the hypersthene giving colours only slightly higher than those of the felspars, and usually grey or pale yellow. The hypersthene is proved to be such by its uniformly straight extinction in sections and in cleavage flakes to the three pinakoidal planes, the emergence of a bi-sectrix, in sections transverse to the *c* axis examined in convergent light, the optic axes lying outside the field, while in sections which show only a parallel cleavage a bi-sectrix can sometimes be seen with emergence of two axes in the edges of the field. The principal axis corresponds with the axis of least elasticity (C=C). Around the axes coloured rings are to be seen in the augites, but not in the hypersthenes.

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As contrasted with the augites, the hypersthene has more frequently a well-defined crystalline form, longitudinal sections being elongated with usually slightly rounded ends. Distinct traces of the terminal faces are not usually to be made out. Transverse sections are squarish or rectangular, and bounded by the pinakoids, the prism faces being present only as slight truncations of the corners. In such sections, when very thin, four directions of cleavage are to be made out; two more perfect and following the prism faces, the others pinakoidal. Longitudinal sections show a parallel cleavage, and sometimes an irregular transverse fracture. The hypersthene is pleochroic, though not very markedly so. C=pale green; A and C= brownish yellow. Occasionally two well-formed crystals are seen interpenetrating and crossing at an angle of about 30°—probably twins on a dome or pyramid face. The hypersthene shows, in most cases, no decomposition. It is fairly rich in enclosures, mostly glass cavities of regular form—negative crystals. In longitudinal section they are rectangular, with often rounded corners; in transverse section eight sided. They contain a brown glass, and often a minute grain of magnetite or rounded immovable bubble. The other enclosures are apatite and magnetite.

The augite occurs in irregular grains with usually no definite crystalline outline and enclosures similar to those of the hypersthene. It is frequently twinned, simply or repeatedly, on the orthopinakoid. Frequently it is associated with the hypersthene, irregularly or in parallel growth. In that case their longitudinal axes coincide. (The augite has an obliquity of extinction of about 45° in clinopinakoidal sections.) The relation between the two minerals in point of priority is not easy to make out, and it seemed that sometimes the one, sometimes the other, was the earlier. The augite is very fresh, and free from decomposition.

The magnetite and iron oxides occur in black grains of rounded form scattered throughout the rock, and especially frequent as enclosures in the pyroxenes.

The apatite is somewhat exceptional. The crystals are sometimes very large, quite as large as many of the felspars (1·8 mm. × ·23 mm.). Some are long, narrow, and transversely broken, others short and stout, six-sided in transverse section, and evidently bounded by a hexagonal prism and obtuse pyramid. They are full of minute enclosures, probably of glass, which in longitudinal sections are elongated and arranged parallel to the axis; in transverse sections they are seen to lie in three series crossing at 60°. The mineral is richly dichroic in shades of red and grey. Similar apatites were remarked in a porphyrite from Allerhope Burn, Cheviots, by Dr Petersen.

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The ground mass under low powers appears to be almost entirely glassy, and to have only a very feeble effect on polarised light. But higher powers show it is really a felted mass of minute microlites lying in a pale-brown glass. Cumulites, globulites, and other growth forms do not occur here as in the Cheviot andesites. The microlites are usually short and stout, and three or four times as long as broad. It is difficult to be quite certain, but I am of opinion both augite and felspar are present of a second generation, and opaque grains of magnetite are scattered everywhere throughout the mass. Unlike the porphyritic crystals, these microlites show no regular parallel arrangement, and must be regarded as the product of crystallisation at a time when the rock had ceased to flow, and was entirely at rest.

Around the larger augite crystals there is everywhere a dark hem or border, which under high powers is finely granular in appearance. These large crystals have been corroded, and at first it seemed probable this border was a product of the same nature as the well-known borders which surround the hornblendes and the micas in many andesites. But it is really due to a regular deposition of the minute augites of the second period upon the surface of the earlier crystals. It is notable that the felspars are without such borders; around the hypersthenes, also, they are never conspicuous, while they surround the augites with such regularity that they serve as a ready means of discriminating between the two pyroxenes. Sections which just graze the surface of a large augite are particularly interesting, as they show a densely packed and tessellated aggregate of microlites planted on the face of the crystal. They may be sometimes seen to form long narrow streams, which start from one of the large crystals, and pass some distance through the ground mass. When the sections are examined in polarised light the colours given are those of augite, and the extinction in both crystal and border is uniform. This is to be explained only by the regular parallel position of the microlites with respect to the crystal they surround, and is not merely due to a thin layer of augite underlying the microlites.

In the ground mass also, and quite apart from the larger crystals, the little augites are seen sometimes to have formed rounded aggregates with no trace of crystalline outline, but giving the augite colours, and with a uniform extinction throughout.

In the ground mass occur also certain rounded bodies which have some resemblance to spherulites. When perfectly formed they have a rounded section. At the periphery they are darker than the surrounding rock; their centre is usually of a distinctly

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lighter shade. They consist of minute microlites similar to those in the rest of the ground mass, and a regular grouping cannot be determined, except that the magnetite grains are sometimes in radial arrangement. Between crossed nicols there is no definite cross, and the radial arrangement is very indefinite. They frequently surround crystals, and are then usually of more irregular form; but they are not products of corrosion, as they surround the various minerals impartially, and the crystal is usually eccentric, and often there is none whatever. Similar bodies are to be seen in the well-known andesite of Bath, Hungary, to which the rock bears an extraordinary resemblance, and are here regarded as a form of kugel structure, which Rosenbusch compares to the variolitic.

It will be seen that this rock bears a very close resemblance to the Cheviot andesites described by Teall and Petersen. From these it differs chiefly in the nature of the ground mass and the presence of kugel structure. Its remarkable freshness in the best specimens and its great similarity to the Hungarian andesites are also points worthy of remark.

The rock itself is to be found beside a little spring about a mile up the Sherriffmuir road from Logie Church. It is well exposed by recent quarrying, and forms a marked cliff running down the hill for some distance, but terminating just to the east of the road. Mr Peach, F.R.S., who mapped this district for the Geological Survey, was good enough to allow me to consult the 6-inch map, on which I found it marked as an intrusive sheet. He found that it bakes and hardens the shaly ash bed overlying it. This I did not remark, but it is easy to recognise the differences between this intrusive sheet and the interbedded lavas of the hill. It ends out very abruptly compared with the manner in which the lavas gradually thin as they pass westwards. Its western end is also very suggestive of an unconformable intrusion into the ash beds, as it seems to pass down across the bedding planes; while it is nowhere vesicular, not even on the upper surface, which in the lavas is everywhere slaggy, and often beautifully ropy and contorted. Specimens were collected from the top surface, as fresh as possible, and these showed no very marked difference from the middle of the sheet, except that the hypersthenes were decomposed into green products; and the ground mass was almost completely filled with kugel bodies both rounded and of irregular outlines. This would indicate that these bodies were somehow connected with rapid cooling and consolidation. No specimens of a completely glassy chilled edge were obtained, the ground mass being essentially similar to that already described, but this is no doubt due to the fact that overlying the andesite is a little valley partly filled with boulder

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clay and thin layers of peat. The exposed surface has much of the appearance of the surrounding porphyrites, being dull and stony, stained green and red with decomposition products. Absolutely fresh material is most easily obtained where this surface has been quite recently removed by quarrying, but often a blow with the hammer is sufficient to remove the weathered crust and reveal the fresh rock beneath. The extreme west end, where the sheet dies out in the ash, yielded the most satisfactory specimens. In microscopic sections of the weathered surface material the various porphyritic minerals all showed decomposition, the felspars being relatively fresh while the hypersthenes were almost entirely destroyed, and it was interesting to observe that while the ground mass between the kugels was often cloudy, dull, and filled with secondary substances, the kugels themselves were comparatively unaffected.

Specimens were collected from the porphyrites of the hill, and microscopic slices prepared for the purpose of making a comparison of their features with those of the andesite. The localities were as follows :—

1. From a small cliff crossing the road in the valley behind Logie Church.
2. The lava immediately overlying the andesite.
3. The lava overlying and as exposed in the roadside.
4. } From small quarries just to the north of 3, and east of
5. } the road.
6. The last porphyrite outcrop to the north ; from a small valley where a burn crosses the road 300 yards N. of 3.

All were porphyritic and not markedly amygdaloidal except on the surface, dull and stony in aspect, stained red and green, the vesicles filled with calcite, chlorite, and agates. All showed fluxion structure, and many were crossed with red veins similar to those in the andesite. Some of these lavas show at their base an immense number of angular baked fragments of sandstone and shale evidently caught up from the sea bottom over which they flowed. The underlying shales were often baked, and the sandstones showed ripple marks and worm burrows.

The felspars were cloudy and stained, and the pyroxenes were green or red, with often a platy structure and a pearly lustre. This mineral was soft and cut readily with the knife. Cleavage flakes showed in some cases the emergence of a bisectrix perpendicular to the cleavage with small and variable axial angle. The extinction in flakes and sections was straight. Hence it is in all probability bastite replacing hypersthene.

Under the microscope the rocks are porphyritic and amygdaloidal and show fluxion structure. In all the phenocrysts are

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more numerous than in the andesite, and the most numerous are the felspars. Their forms and optical characters are similar to those of the felspars in the andesite. Their numerous dark glass cavities are often arranged in a marginal zone. They are cloudy, and in their cracks calcite, limonite, and green chloritic minerals have been deposited. Yet they are in all cases sufficiently fresh to show their characteristic twinning and interference colours. The pyroxenes on the other hand are relatively far more decomposed. In most cases they have been replaced by secondary products, of which the bastite is the commonest. The fibrous appearance and straight extinction, together with the fact that it forms well marked pseudomorphs after hypersthene, distinguish it readily. Four-sided transverse sections with blunted corners are very numerous, and the transverse cracks, the glass cavities, the parallel growths, and the cross twins can all be distinguished. The fibres of the mineral are parallel to the long axis of the original crystals, and between them minute brown platy enclosures are frequent. The extinction is parallel to these and to the pinakoids, though this is true only in a general sense, as around the margins and cracks of the original crystal the fibres are usually irregular in arrangement. The colour varies from pale green to a rather deep brown, and in the latter form it is often markedly dichroic. Fresh augite was not observed, but the numerous pseudomorphs of irregular outline, consisting of a pale green chlorite with irregular fibrous structure, and yielding low polarisation colours, probably represent original augites, especially as they are often associated with the bastite pseudomorphs in a manner similar to that of the pyroxenes in the fresh rock. Calcite and limonite are very abundant, and with quartz form the ultimate products of decomposition.

The ground mass varies considerably. It is obscured by decomposition and the deposit of secondary products. I have been unable to find in any the kugel-structure of the fresh type. Perhaps the most similar to that rock is No. 6, in which the ground mass has a hazy appearance and is filled with minute grains of magnetite and microlites of indefinite form. It is still largely isotropic and must at first have been mainly glassy and hyalopilitic, but the phenocrysts are relatively more abundant than in the andesite. The other rocks are characterised by the presence in the ground mass of felspars of a second generation, which often have the swallow-tailed ends and the wisp like forms due to rapid crystallisation. They lie in streams which wind round the larger crystals. A second crop of augite was not determined with certainty. The ground mass is always dull, cloudy, and somewhat opaque.

These rocks have evidently been originally glassy, or largely

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glassy hypersthene andesites, very similar to the fresh rock described, and the conclusion seems inevitable that they have all proceeded from a common source and are of a similar geological age.

In that case we have here a rock of Old Red Sandstone age, which can in no respect be separated from the modern Andesites of Hungary and of North America. Its remarkable state of preservation is perhaps in part accidental, but no doubt also due to the glassy and impermeable condition of the ground mass.

[In Sir Archibald Geikie's "Ancient Volcanoes of Great Britain" (Vol. I. p. 275), a pitchstone-like Hypersthene Andesite from near Airthrey Castle is mentioned and described from notes by Mr Watts. No doubt this is the same rock as that described in this paper. Sir Archibald Geikie's book was published before this paper was read, and while it was lying in the hands of the Society's Committee.]

Explanation of the Figures.

Plate XVII., Fig. 1. Magnified 25 diameters.

The upper part of the field is occupied by a large crystal of augite which is simply twinned. Its outlines are very irregular, as the result of corrosion. It encloses magnetite, apatite, and minute glass cavities which often contain a bubble. It is surrounded by a granular border consisting of minute augites of the second generation in parallel position. Beneath it is a hypersthene crystal in longitudinal section, relatively more idiomorphic and without the granular border. The white crystal below is plagioclase felspar.

Fig. 2. Magnified 24 diameters.

The rounded mass is one of the 'Kugel' structures with a dark periphery and pale centre. There is little trace of radial structure except in the disposition of the minute dark crystals of magnetite.

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XLIV.—*On the Laws that Govern the Rounding of Particles of Sand.* By Wm. Mackie, M.A., M.D. (Plates XVIII. and XIX.).

(Read 29th April 1897.)

In my inquiry into the origin of the sandstones of Eastern Moray I have had frequent occasion to note the various degrees of rounding presented by the various mineral particles that enter into their composition. During the last three years I have examined a large number of specimens from all the sandstone formations represented in the area, and from all important divisions of these formations. Amid much that was variable in the highest degree, it soon became evident that so far as the rounding of the constituent particles was concerned, a certain amount of uniformity prevailed, and though from a very early period of the inquiry it was no less evident that quite a number of factors entered into and co-operated to produce the results observed, it was nevertheless soon recognised that these results were fairly constant, and in the majority of cases strictly comparable from specimen to specimen. In order if possible to discover guiding principles, the better to compare past with present conditions, and generally it might be to illustrate both, I examined the sands of the rivers of the adjoining land area, the sands of the shore of the Moray Firth, and the sands of the sand dunes of Culbin. All these, though often in less degree, appeared to illustrate the operation of the same general principles. It was very early noted that the size of the particles within certain fairly defined limits at either end had a decided bearing on their degree of rounding. Over and over again it was observed that the larger grains of a sand or sandstone are usually the more rounded. Only once, or at most twice, has an exception been noted in beds at the very base of the Upper Old Red series. In many cases, even in the same specimen, in passing from the smaller to the larger grains, the transition from angular to rounded forms was found to take place quite suddenly. A very slight increase in the diameter of the particles often made all the difference between roundness and angularity. The degree of rounding was therefore apparently not in the simple ratio of the diameters of the grains. Size naturally suggested

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weight as an element in the case, and when particles of approximately equal size but of different specific gravities were examined side by side in the same specimen, it was found to be the general rule that the particle of higher specific gravity was the more rounded. Thus, of fragments of quartz and zircon of nearly equal size, the zircons would in nearly all cases be out of all comparison the more rounded of the two groups. Then, again, it was observed that where the size as well as the specific gravities of the particles were practically equal, but an appreciable difference existed in their degrees of hardness, it was generally found that the particles of the mineral with the lower degree of hardness were in the vast majority of instances the more rounded of the two. Thus, where all the particles of a sand or sandstone exhibited a certain degree of rounding, the felspars would almost always show more rounded forms than the quartz grains. Here it will be observed that the amount of rounding is in the indirect ratio of the hardness of the mineral. Another factor in the results, and one that naturally suggests itself, is the distance over which the different particles have travelled. Of this, of course, in most cases there was little chance of judging; but where the origin of particles could be determined with more or less exactness, the greater distance of travel coincided in a large number of instances with the greater degree of rounding. Exceptions occurred. Thus it was observed in the case of a particular class of grains—the quartz grains of the Netherly diorite near Rothes—that in L.O.R. beds, fourteen miles in direct line from the parent rock, they were always found perfectly angular, while in the U.O.R. beds, only five miles away, they were almost always beautifully rounded, and in still another series of undetermined age, but in microscopical characters agreeing most closely with the L.O.R. beds—I mean in the *Asterolepis* beds, Nairn—at twenty-five miles distance they were present in fine grains, conspicuous by their roundness among the generally angular debris of that rock. Then, again, the constituent particles of sandstones of undoubted L.O.R. age were found to be invariably angular, of the U.O.R. series to be of mixed character, rounded and angular grains occurring in varying proportions in the several divisions of the group, and even in different beds of the same division, of the 'Reptiliferous' beds, to be all of them, small and large alike, rounded to a degree to which no parallel could be found among recent sands, while in the small portion of Oolitic sandstone falling within the area, they were again angular in the highest degree. These observations suggested differences in the agents of transport as well as variations in the conditions of deposit, and when in relation to the rounding process the action of the

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agencies known to us came to be investigated, it was at once seen that the sands of Culbin, which owe their form largely to the action of wind, were, after a transit of only a few miles, much more rounded than sands of the same degree of fineness after many miles of water carriage, and much more rounded even than the same sand after prolonged churning by the waves in the tide-wey of the sea-shore. It was thus evident that at least five factors were concerned in the result:—

(1) The size of the particles.
(2) Their specific gravity.
(3) Their hardness.
(4) The distance over which they had travelled.
(5) The agent by which they had been transported.

The amount of rounding of a particle varies directly as (1) (2) (4); and indirectly as (3). We may therefore express the total amount of rounding (R) as proportional to or varying with the size of the particle multiplied by its specific gravity, multiplied by the distance it has travelled, the whole divided by its hardness, thus—

$$R \propto \frac{Size \times specific\ gravity \times distance}{Hardness}.$$

Size and specific gravity come together as weight or mass. Thus the weight of a cube of which the side is x is expressed by x^3spg.

Distance of travel is more accurately expressed as the number of times the particle has turned on its axis in covering the stated distance (d). This is easily expressed, as the distance divided by the rolling circumference of the particle. It is to be supposed, of course, that in each revolution the same amount of work towards the rounding process is done. This, however, is only approximately true, as the weight of our hypothetical particle is gradually lessening, and its rolling circumference slowly changing in outline as well as lessening in amount. But as these two effects tend to balance one another, $\frac{distance\ travelled,}{rolling\ circumference\ of\ particle}$ will fairly represent the number of revolutions of particle in covering the distance d. For our hypothetical cube this will be $\frac{d}{4x}$. Substituting these quantities we get $R \propto \frac{x^3spg.\ \frac{d}{4x}}{h.} = \frac{x^2spg\ d}{4h.}$ (or generally $\frac{x^3spg\ d}{mh}$ where m varies with outline of figure).

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This is the result for a cube. For other figures the result is much the same, only the coefficient of h varying. For a sphere the coefficient of h would of course be 3·1416, which is the lower limit of variation. For all symmetrical figures the coefficient of h could be easily determined, but as the particles with which we have to deal are for the most part of very irregular, of very different and indeterminate shapes, the coefficient of h may be neglected altogether. It is only in the case of idiomorphic particles that it need be considered at all.

The above result shows that for particles of the same substance of the same form but of different sizes, distance remaining constant, R varies as the squares of their diameters. For particles of different substances, size, shape, and distance being constant, R varies as

$$\frac{\textit{the specific gravity of the particles}}{\textit{their hardness}} = \frac{spg}{h}.$$

This gives a different value for each mineral, but one which is practically constant for the same mineral. Such value may be called the coefficient of roundability,[1] or the specific "roundability" of the particular mineral. The values for a few of the commoner substances observed in sands have been calculated out in the table given below. The above formula $\frac{spg}{h}$ holds for air. For water a slightly different formula obtains. All bodies lose weight in water by an equal volume of water. The weight of our hypothetical cube in water would therefore be $x^3(spg-1)$, so that the coefficient of roundability becomes for water $\frac{spg-1.}{h}$

This, when calculated out, gives of course a series of lower values for the different minerals.

In calculating out the following table the average of all the specific gravities and the average of all the hardness values given opposite the different minerals in Dana's System of Mineralogy, 5th edition, have been used.

[1] This is a terrible hybrid. A classical friend to whom I applied suggests "*Strongylicity*" (from στρογγύλος, round, or στρογγυλίζω, I make round.) This word has a *strong* Saxon aroma which would be likely to be suggestive of qualities of a different order. My own inclination is to "*psephicity*" (from ψῆφος, a pebble), naturally meaning *facility for being made into pebbles.*

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Table of Relative "Psephicities."

Mineral.	In Air. $\frac{Spg.}{h}$	In Water. $\frac{Spg-1}{h}$
1. Quartz,	·38	·23
2. Orthoclase,	·4	[Kaolinite 1·4] ·29
3. Andalusite,	·42	[Compact varieties: Impure much less].
4. Tourmaline,	·43	·3
5. Labradorite,	·45	·29
6. Staurolite,	·5	·36
7. Garnet,	·53	·39
8. Hornblende,	·57	·39
9. Zircon,	·59	·45
10. Kyanite,	·6	·43
11. Sphene,	·66	·7
12. Rutile,	·68	·51
13. Magnetite (as type of iron ores),	·86	·7
14. Biotite,	1·05	·7
15. Chlorite,	1·2	·76
16. Muscovite,	1·3	·86

Observation over a comparatively large number of examples generally confirms the theoretical order given above as the order which approximately obtains in nature. It is of course impossible to eliminate differences in the distances of travel of the different particles or even to make any but the roughest allowance for relative size, but when this has been done some exceptions to the theoretical order are found to exist. Such exceptions are frequently traceable to some peculiarity of the particular mineral, oftener perhaps to errors of specific determination in the mineral groups.

Among some of the peculiarities of minerals that give rise to exceptions, the following may be mentioned:—

(1) *Susceptibility to chemical change.* This usually operates in the direction of lowering their hardness, and it is possible that if the appropriate correction in this respect could be made they would still be found to fall into line. Felspar when highly kaolinised, as it is for most part in river sands, gets rounded too quickly and is an exception coming under this heading.

(2) *Certain conditions of cleavage.* Some minerals seem to exfoliate along their dominant cleavage plane under the rounding agencies and thus continue to present angular outlines. Their ultimate fragments appear however to obey the law. Horn-

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blende, and to less extent felspar, are exceptions in this respect.

(3) *Vesicular habit* or the presence in a mineral of large numbers of liquid or gas pores seems to increase its tendency to angularity This may be due to the fact that the specific gravity is thereby reduced. But it is manifestly not the whole case. Why, for instance, should garnets be found in some sands—notably the Culbin Sands—in very small and markedly angular grains? It is interesting to remember in this connection that the probable tendency of vesicular quartz to disappear was one of the results of my previous paper.

(4) *Variations of original outline.* This applies only to idiomorphic particles and is fully covered by the varying coefficient of h in the general formula. It explains why a crystal of zircon should be more speedily reduced to a rounded form than a crystal of magnetite. Zircons, however, are frequently seen in their original matrix in the crystalline rocks as rounded blebs without any trace of crystalline outline. This would explain the marked tendency of zircon to come out too high in the results which have been worked out below. Originally idiomorphic zircons take on characteristic spindle-like forms after a certain degree of rounding.

(5) *Very high degrees of hardness* probably give rise to new conditions. Particles appreciably harder than quartz, from failing to come in contact with substances as hard as or harder than themselves, would not be likely to be sensibly changed in shape after a very long journey. Thus topaz would have a coefficient of ·44 in the column for air and of ·31 in the column for water—that is to say, greater than quartz in both cases; while the coefficient of diamond would be ·35 in air and ·25 in water, or less than quartz in air and slightly greater than it in water. I have observed what I believed to be one or two microscopic topazes in the matrix of a L.O.R. conglomerate at Gollachy Mill. Their crystalline outline was perfect, but the same was true of some of the garnets that were present in abundance in the same specimen. With the behaviour of the diamond, under these conditions, I have no acquaintance; but it is certainly not to be expected that it is more susceptible in this respect than quartz. After all, the case is probably not limited to a problem in pure friction, but includes the results of direct impact as well. In that case a certain degree of rounding may be expected, even in the very hardest minerals. Reference is sometimes made in books to the frequency with which zircon and rutile occur in idiomorphic forms in sands, due, it is supposed, to their hardness. No doubt they do so occur, but so also do garnets many times their size, and the

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occurrence of fragments of felspar, bounded by regular cleavage planes, is not infrequent, both in sands and sandstones. If it were the habit, and not the exception, for quartz to occur in idiomorphic form, we should no doubt frequently find it so occurring in sands. It has been suggested, on the other hand, that idiomorphic zircons and rutiles have been liberated *in situ* by the decomposition or breaking up of muscovites or biotites, in which they formerly existed as inclusions, and in which they had been carried to the position where they are now found. As micas have been repeatedly observed both in sands and sandstones, with crystals of zircon and rutile on the point of dropping out of them, while others have been seen showing empty spaces, with the regular outlines of these minerals from which they had presumably already dropped, the latter view seems at least to contain a modicum of truth.

(6) *Difficulties of specific determination* probably account for not a few anomalies. Thus tourmaline and hornblende are not always easily distinguished. With nearly spherical particles it is manifest that the occurrence of the darkest pleochroic tint, when the long axis of the polarising prism is parallel to or at right angles to the *long* axis of the fragments, has really no meaning, and a little reflection will show that, even where there is a longer and shorter diameter in our hypothetical particle, these differences need not be absolutely diagnostic of tourmaline or hornblende. Many particles are also too thick to show reliable pleochroic differences. With a little experience, however, it is usually possible to decide, with more or less accuracy, from the general characters of the respective minerals. Again, what are put down as "iron ores" in the following determinations are manifestly not all iron ores. Opacity, which has been taken as the determining characteristic, may cover fragments of organic matter or particles of minerals not transparent, unless of an excessive degree of thinness. Hence this is one reason why the iron ores, in all the specimens which have been discussed in detail, come out relatively too low.

(7) *The impurity or composite character of the mineral fragments* also accounts for some anomalies. The iron ores also come under this heading. More frequently than other minerals, these have been observed to carry fragments of the matrix of the original rock along with them. These being mostly of quartz or felspar tend to reduce the specific gravity of the composite particle, and hence bring out the result too low. They also interfere with the regularity of the rounding process, which naturally leads to a like result.

(8) *Idiosyncrasies of some minerals.* Thus magnetite, from its attracting other particles, is apt, in transmitted light, to give

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Fig. A. (× 30)
Quartz Grain, from Quartz-Mica Diorite, Netherly, Rothes
Showing numerous (Rutile?) needles.

Fig. B. (× 50)
Quartz Grain showing Cleavage Structure, from Glengrant Granite.

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the impression of a single angular fragment, whereas what is really observed is an aggregate, made up of several rounded fragments.

Most of these exceptions, it will be seen, arise from the difficulty or impossibility of precise determination on the objective side, and it is reasonable to suppose that if greater precision were attainable in this respect, an even closer conformity to law than is observed would be easily demonstrated. At the same time it is worth noting that there are some minerals that, were we to decide the question on *a priori* grounds, would be naturally ranked as exceptions which are found to be in notorious conformity to law. Such a mineral is muscovite. The flat plates of this mineral are the first to show the rounding process, and appear in many sandstones, and notably in sea sand, as ovoid or nearly circular discs. From this result it would appear that they have a tendency to get on their edges and be trundled along by the current, somewhat after the manner of a boy's hoop. Biotite exhibits the same peculiarity, but though it comes out relatively to the muscovite invariably in the right position, still, in relation to the other minerals it is always too low. This is due to its higher susceptibility to chemical change and consequent greater friability, so that in the preliminary treatment of a sand it readily goes to pieces. It is frequently met with in crescentic fragments with one border rounded, the other frayed and irregular, due to the breaking up of originally rounded plates.

Several examples of sands and sandstones containing a proportion of heavy particles have been worked out in detail, and the relative amount of rounding of the several mineral groups noted. The list of minerals thus worked out—though it must be admitted by a highly artificial method—follow more or less closely the order derived from calculation. Such exceptions as occur may be readily explained by actual differences in the average size of the particles of the several mineral groups, by possible differences in the relative distances over which they have been carried, or by the operation of one or more of the subsidiary causes just described.

I. The first specimen of a sand examined in detail was one exceptionally rich in heavy particles, which I found in the collection of the late Dr Gordon, of Birnie, labelled "*Amethystine and Iron Sand, shore at Macduff*, 1850." It was found to contain 41 per cent. of opaque particles, presumably in large part iron ores, 37 per cent of garnet, 7 per cent. zircon, 6 per cent. staurolite, 1 per cent. quartz; and the remaining 8 per cent. was made up of kyanite, tourmaline, hornblende, hypersthene, and other undetermined fragments. In this specimen the characters

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of the different particles as regards roundness or angularity were observed and noted, as shown in the following table:—

Mineral Particles.	No. Observed.	No. Rounded.	No. Subangular.	No. Angular.	Average Rounding.
Staurolite,	31	—	8	23	1·26
Garnet,	65	19	12	34	1·77
Opaque [Iron ores],	72	20	18	34	1·8
Zircon,	31	19	7	5	2·45
				Average rounding represented by	1·82

The numbers in the last column are obtained by counting 3 for a rounded particle, 2 for a subangular, 1 for an angular, and dividing out the sum by the number of particles in each group —a highly artificial method, but one that facilitates comparison of the different groups one with another. Here the iron ores are out of place, and the zircons relatively too high—in all probability for reasons that have been already detailed.

II. A sample of river sand from the Spey at Craigellachie—*i.e.*, just before the river sand can possibly get contaminated by admixture with particles derived from the sandstones, was found, from its general angularity, to be incapable of numerical treatment, but its general characteristics were as here described. No appreciable rounding of the quartz grains was observed, though they certainly did not all of them present the marked angularity of the quartz grains in most boulder clays. The felspars also were angular. Some of them being kaolinised in a high degree, did exhibit considerable blunting of their angles. The flakes of chlorite were generally rounded, but presented rather frayed, irregular edges. The muscovites showed some rounding of their prominent angles, but were generally of irregular outline. The same description applied to the biotites. Hornblende was present in minute ragged-edged fragments that showed no tendency whatever to rounding. Garnets were notoriously angular. The zircons occasionally showed ground glass surfaces, but were generally angular. These results fairly conform to law, but they are really so trivial as to prove nothing. Still they must represent, so far as the rounding process is concerned, in at least a proportion of the particles, the net result of not less than 70 miles of water carriage.

III. A very fine grained sandstone from the slab of *Holoptychius* found at Cuttieshillock, now in the Elgin Museum, and presumably belonging to the U.O.R. series. This specimen was found to be very rich in heavy particles. These were roughly separated by the method of Carus Wilson,[1] and the micas in

[1] *Nature*, vol. xxxix. p. 591.

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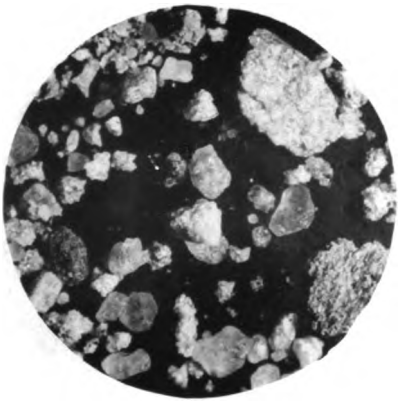

Fig. 1. (× 10)
Matrix of L.O.R. Conglomerate.
Gollachy Mill, Port Gordon.

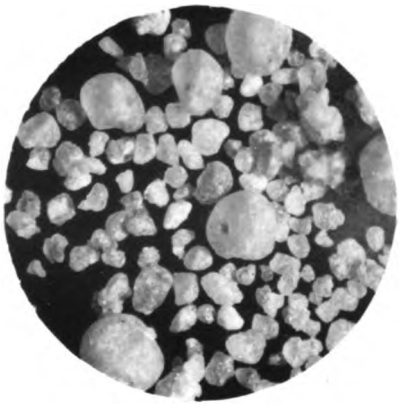

Fig. 2. (× 10)
Slab of Gordonia Duffiana,
Elgin Museum.
From Reptiliferous Sandstone of
Cuttieshillock.

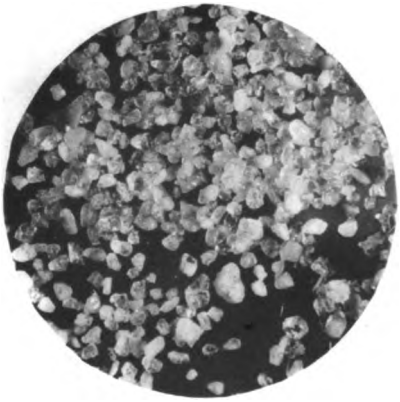

Fig. 3. (× 10)
Culbin Sand.

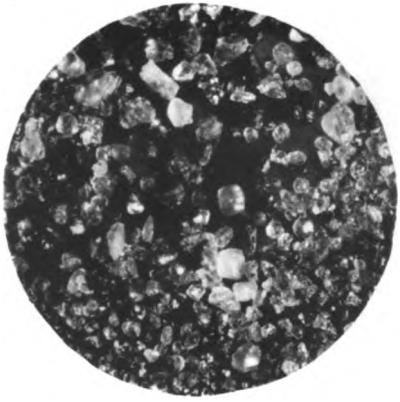

Fig. 4. (× 10)
Garnet Sand, from Shore near Macduff.

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another sample by levigation, and examined with the following result:—

Mineral Particles.	No. Observed.	Rounded.	Sub-angular.	Angular.	Average Rounding.
Tourmaline,	17	4	9	4	2
Biotite,	36	9	16	11	2
Opaque [Iron ores],	34	17	7	10	2·2
Zircon,	72	40	16	16	2·3
Sphene,	21	10	9	2	2·4
Muscovite,	71	48	18	5	2·5
Felspar,	56	23	16	17	2·1
Quartz,	58	14	14	30	1·7
			Average rounding represented by		2·15

The quartz and felspar particles were at least twice the diameter of the other particles, and some allowance must be made for this. The opaque particles are again too low to be exclusively iron ores. Biotite is relatively to the muscovite in its right position, but is relatively too low as compared with the other minerals. The probable reason of this has been already given.

IV. A specimen from the Culbin Sands. This particular sample was fairly rich in heavy particles. Great differences in this respect have been observed in these sands, as also in regard to the general degree of rounding of the particles presented by different specimens, though it has, no doubt, been marked in all. At present I can only offer tentative reasons for these differences. The following results were obtained in the specimen examined:—

Mineral Particles.	No. Observed.	Rounded.	Sub-angular.	Angular.	Average Rounding.
Staurolite,	2	—	—	2	1
Kyanite,	2	—	1	1	1·5
Garnet,	45	13	14	18	1·9
Hornblende,	5	3	1	1	2·4
Tourmaline,	13	8	4	1	2·5
Opaque [Iron ores],	10	7	3	—	2·7
Sphene,	9	8	—	1	2·8
Zircon,	7	7	—	—	3
Felspar,	16	10	5	1	2·6
Quartz,	16	6	9	1	2·3
			Average rounding represented by		2·27

Here the order is very much in accordance with law, but the number of particles in some of the groups is too small to insure

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a fair average. The quartz and felspars were here also much larger than the other fragments.

V. A specimen of sand from the sea-shore, in the sandy reach midway between Lossiemouth and Covesea, was found to be very poor in heavy particles. This sand gave the following results:—

Mineral Particles.	No. Observed.		Rounded.	Sub-angular.	Angular.	Average Rounding.
Hornblende,	10		—	5	5	1·5
Kyanite,	2		—	1	1	1·5
Biotite,	16		3	7	6	1·8
Opaque (Iron ore),	3		1	1	1	2
Chlorite,	4		1	2	1	2
Muscovite,	20		7	9	4	2·2
Quartz,	38	A proportion of these evidently derived from the sandstones of the coast.	6	13	19	1·7
Felspar,	26		8	13	5	2·1
		Average rounding represented by				1·8

VI. A specimen from the Reptiliferous of Cuttieshillock was found to be notoriously poor in heavy particles. So was a second specimen from the slab of *Gordonia Duffiana* in the Elgin Museum. [It is interesting to compare specimen No. III. with this. The difference as regards the number of heavy particles present is certainly remarkable.]

Mineral Particles.	No. Observed.	Rounded.	Subangular.	Angular.	Average Rounding.
Tourmaline,	1	—	1	—	2
Opaque (Iron ores),	6	4	2	—	2·7
Zircon,	5	5	—	—	3
Rutile,	1	1	—	—	3
Quartz,	43	33	11	1	2·7
Felspar,	25	20	2	3	2·7
		Average rounding represented by			2·7

The quartz and felspar here come out equal. This confirms a previous impression that the felspars were more frequently found angular relatively to the quartz particles than in any other formation. The general percentage of felspar in this series being low, the reason probably is that most of the felspars, having been ground to dust, only those that have been carried a relatively short distance remain, and these in consequence are in large proportion angular.

VII. A sample from the matrix of the L.O.R. conglomerate, Gollachy Mill, was examined. The particles of this specimen

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were generally so angular that results were not represented numerically. It showed a small number of heavy particles, among those being zircon, usually in idiomorphic, but occasionally in spindle-shaped forms. The iron ores were mostly subangular. The garnets were in angular fragments, but some of them showed idiomorphic outlines. Staurolite was present in markedly angular fragments, frequently showing chonchoidal fracture. The muscovites were many of them rounded, while some of the biotites showed crescentic edges. The felspars were generally angular, though an occasional fairly rounded specimen was seen. Of the quartz grains some approached subangularity, The degree of rounding of these latter, though not much, was certainly higher than in the specimen of river sand above described, and the same remark applies to the average degree of rounding of the particles. In this specimen a large number of very angular fragments of a dark indigo-blue schist were separated among the heavy particles. Similar fragments, but of much less intensity of colour, have been observed in the sand of the river Fiddich—in fact the whole facies of the particles of this specimen have a remarkable resemblance to the sand of that river. The blue fragments have been provisionally referred to ottrelite, and their angularity is ascribed to their breaking up during the preliminary treatment of the sand, some regular crystals possibly to be referred to barytes, and evidently of secondary origin, were also observed in this specimen.

Collating the averages of these results we get:—

For	II. River sand of Spey, represented by a number not much over, ...	1
„	VII. L.O.R., Gollachy certainly higher, but not, .	1·5
„	I. Garnet Sand, Macduff, . . .	1·8
„	V. Sea Sand, Lossiemouth, . . .	1·8
„	III. Upper Old Red; Holoptychius Slab, .	2·15
„	IV. Culbin Sands, ...	2·27
„	VI. Reptiliferous, Cuttieshillock, . . .	2·7[1]

It will thus be seen that the two highest results have been obtained, in the one case where the rounding of the particles is known, in large part, to be due,—in the other, where it is believed on hypothetical grounds to be due to the agency of winds.

This leads us to investigate why wind should be a more potent agent in the rounding process than water. In air the particles roll with their full weight. In water they lose weight, by the weight an equal volume of water, so that in water they

[1] These numbers are not in any way proportional to the degree of rounding of the several specimens. If we subtract 1 from each number the results should then be approximately proportional.

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roll with only a fraction of their weight. This is one reason why much larger particles are moved by water than by wind. It should be remembered, however, that in the rounding of the larger particles or pebbles, it is only the exceptional force of the current that is concerned, whereas in the case of wind, a relatively large proportion of the work of rounding is probably done at comparatively low velocities.

To compare the relative efficiency of wind and water as rounding agents, we have—

$$\text{For wind, } R \propto \frac{x^2 spg\, d}{mh}, \quad \text{for water, } R = \frac{x^2(spg-1)d}{mh},$$

$$\therefore \frac{\text{wind agency}}{\text{water agency}} = \frac{spg.}{spg.-1} \text{ or, for quartz} = \frac{2{\cdot}65}{1{\cdot}65},$$

$$\text{or, wind} = 1{\cdot}6 \text{ times water.}$$

But it is very evident, I think, that the relation is not of the simple kind now stated. The momentum of the moving particles at the time of impact must be taken into account—in other words, the amount of rounding will be in proportion to their capacity for work that is as $\frac{1}{2}mv^2$. Now $m = x^3 spg$ for air, and $x^3(spg-1)$ for water. So that $\frac{\text{wind agency}}{\text{water agency}} = \frac{\frac{1}{2}x^3 spg\, v^2}{\frac{1}{2}x^3(spg-1)v_1^2}$, where v and v_1 are the velocities of wind and water respectively. This cancels down to $\frac{\text{wind agency}}{\text{water agency}} = \frac{spg\, v^2}{(spg-1)\, v_1^2}$. Now as spg is always greater than $spg-1$, and v than v_1, the effect of wind over water must be marked.

Take the following hypothetical case for a particle of quartz of spg 2·65, the velocity of water being two miles an hour and wind eight miles an hour. What is the relative efficiency of the two agents?

$$\frac{\text{wind agency}}{\text{water agency}} = \frac{2{\cdot}65 \times 64}{1{\cdot}65 \times 4} = 29 \text{ nearly,}$$

$$\text{or wind} = 29 \text{ times water (nearly).}$$

From the law of squares already worked out, this will mean that under the conditions stated, particles less than $\frac{1}{5}$th the diameter of those rounded by water will be rounded to an equal degree by wind.

These are no doubt somewhat surprising results, but I am convinced that the difference between the two agencies in relation to the rounding of particles of sand is much greater than is generally supposed.

Note.—The relation of the size of a particle to the force required to move it is expressed by $x^3 spg \propto x^2 v^2$, x being the

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side of a hypothetical cube. Supposing the substance to be constant this becomes—

$$\left\{\begin{array}{l} x^3 \propto x^2 v^2 \\ = x \propto v^2 \\ = \sqrt{x} \propto v \end{array}\right\} \text{or } x^3 \propto v^6.$$

That is to say, the carrying power of wind or water varies as the 6th power of the velocity—a result, I believe, already arrived at for water (Prestwich, *Geology*, vol. i. page 83), but I have not been able to consult the reference there given.—Quart. Journal Geo. Society, vol. iv. pp. 92-93.

Starting with $\sqrt{x} \propto v$ (a much easier formula to use), we have an index of the velocity of the wind necessary to move a particle. Thus the Culbin sand is mostly about $\frac{1}{100}$ inch in diameter, but exceptional samples are found containing grains up to $\frac{4}{100}$. These, however, are less rounded than the $\frac{1}{100}$, showing that winds of sufficient velocity to move the latter are exceptional at the present day. In the Reptiliferous of Elgin, we have grains up to $\frac{8}{100}$, and these are more rounded than the $\frac{1}{100}$ of the present Culbins. If we take $\frac{1}{100}$ as representing the particle moved by the mean average velocity of the wind, say 10 miles per hour, then we have the diameters, being respectively as 1, 4, 8.

For Average Culbin Sand, $\sqrt{1} = 1 \times 10 = 10$

„ Largest Culbin Sand, $\sqrt{4} = 2 \times 10 = 20$

„ Largest Reptiliferous, $\sqrt{8} = 2{\cdot}83 \times 10 = 28{\cdot}3$ miles per hour, as the velocities required to convey them.

These results are only to be taken as approximate, but observations are in progress that make for establishing a more correct result. It may be concluded, however, that winds over 25 miles an hour in velocity were a much more frequent occurrence in Reptiliferous times than winds over 20 miles an hour are at the present day.

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XLV.—*Geological Notes on the Excavations at the Leith Dock Extension*, 1897. By J. G. GOODCHILD, H.M. Geol. Survey, F.G.S.; Curator of the Collections of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art.[1]

(Read 29th April 1897.)

A LARGE area contiguous to the Old Docks at Leith has lately been enclosed for the purpose of extending the accommodation for shipping there. This enclosed area has been drained, and excavations are now being made there to a depth of about 25 feet below low-water mark. The strata exposed consist almost entirely of superficial deposits. The uppermost of these are well-bedded and rather fine-grained quartzose sands, which are interstratified at irregular vertical intervals with thin bands of loam. There is very little false-bedding seen. A few impersistent bands of fine gravel occur in places. None of these strata exhibit any signs of such disturbances as might arise from the impact of floating masses of ice. Towards their base these beds are somewhat more loamy. Their total thickness varies with the form of the beds next below, but it nowhere much exceeds 15 feet.

The included organic remains consist chiefly of mollusca, of which nearly fifty species have been noticed. Their facies is identical with that of the mollusca occurring on sandy bottoms, within the laminarian zone on the East of Scotland in general. They occur in variable quantities on different platforms, most commonly, however, within the upper few feet; but the same assemblage of species prevails throughout. Many of the shells occur in their natural positions of growth; while a fairly large proportion may have been washed up from the lower laminarian zones during storms, or have been transported on seaweed; and others, again, which are of a peculiarly littoral type, may have worked downward from the shore-line under the influence of gravitation. Some interesting biological problems were suggested by an examination of these organic remains. An account of these by the present writer, including a list of the mollusca

[1] In accordance with instructions received from the Council of the Geological Society of Edinburgh, Mr James Currie and the writer of this undertook to report on the excavations referred to in the title of this communication. After one joint visit, Mr Currie requested the present writer to report alone.

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observed, and some remarks upon the early history of the marine invertebrate fauna of the Forth, appear in the Transactions of the Royal Physical Society, vol. xiii., to which reference should be made by those who may desire further details, especially in regard to the mollusca.

There is nothing in either the nature of these sands or their organic contents to show that they have any claim to a high antiquity. For aught one can say to the contrary, the whole of the deposit might have been formed within the last few hundred years.

These sands lie abruptly, and without the slightest trace of a passage, upon beds of glacial origin, to be presently referred to in more detail. The abruptness of the change is, doubtless, to be attributed to the fact that there have been several uprises of the land since the close of the Glacial Period, each of which, by increasing the gradient of the river bed, and thereby accelerating the flow of the water for the time being, has led to the removal at successive periods of the several deposits previously laid down.

At the bottom of all the superficial deposits there occur, here and there, some small exposures of Lower Carboniferous sandstones and shales, which it is very likely may pertain to the Granton Sandstones and the overlying Wardie Shales. A small exposure of oil-shale, similar in general appearance to that occurring in the Wardie Shales in the Craiglockhart Cutting, on the north side of the Suburban Railway Station, was touched in some of the deeper excavations.

The boulder clay is probably the stratum of chief interest in the present excavation. In its general aspect this deposit does not differ very materially from the till of the lowland areas of the Lothians in general. A dark grey sandy clay, tough and extremely difficult to work when freshly exposed, filled almost everywhere with a pell-mell assemblage of stones of all kinds, shapes, and size (in the proportion, roughly, of 40 per cent. stones to 60 per cent. matrix), massive nearly everywhere, or, at the most, shewing only obscure traces of bedding, locally diversified by irregular nests and pockets of gravel mixed with clay like the bulk of the mass—in all these particulars the boulder clay at Leith agrees well with the normal till of the land areas adjoining.

In one or two important respects, however, this boulder clay does differ from the normal till. This latter rock, in the basin of the Forth especially, usually contains, nearly uniformly distributed throughout at least its lower parts, a fairly high percentage of well-glaciated stones; and usually also it includes but a small percentage of stones upon which more or less

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evident traces of glacial wear cannot be detected. Moreover, the normal till of the Basin of the Forth has not yet been proved to contain any stones which have clearly not been derived from areas either within the watershed or from the country lying to the west of that. The boulder clay at Leith, on the other hand, is variable in this respect—some parts yielding a considerable number of well-glaciated stones congregated together, and with only a very small percentage not shewing more or less evident traces of glacial wear; while in other parts of the boulder clay there is a singular rarity of such glaciated material—a large percentage being angular and more or less unworn in aspect. Furthermore, although fully 90 per cent. may well have come from areas within the basin of the Forth, or, at any rate, from some part of the region over which the Ice Sheet is known to have moved, other stones occur whose origin cannot be pointed out with any approach to certainty. Amongst the rocks of doubtful origin, there were at one spot many angular blocks of a peculiar saccharoidal sandstone, some creamy white, and superficially resembling statuary marble, others of a similar texture but of a bright red colour. These are identical in appearance with some rocks associated with the Caledonian Old Red not far from Montrose. With these occurred a boulder of andesitic lava like, it is true, one of the forms common in the Ochils, but containing agates of the type most commonly found near Montrose, and not known in the Ochils. It will naturally occur to most people at first to regard these as possibly having been derived from the Ochils, instead of from a source outside of the Forth; but in the same boulder clay occurred at least three examples of gneiss, which I carefully examined on the spot. One of these was nearly identical with the epidositic gneiss of *Iona*, a rock which owes its special characteristics largely to hydrometamorphism which has taken place immediately below the base of the overlying Torridonians. No rock at all like this is known to occur anywhere within the area traversed at any time by the Forth branch of the ice sheet. There was also a block of augen gneiss, and another of granulitic garnetiferous gneiss. None of these shewed any signs of having been derived at secondhand from an older conglomerate such as occurs at the base of the Caledonian Old Red. I also picked out one small chip of a Chalk Flint. If these came, as I suppose, from areas outside the Forth Basin, there is an additional reason for referring the rocks mentioned above to sources outside of the Forth also. The great majority of the other boulders were of Dolerite, and were mostly of the type occurring at Queensferry and Cramond. Schists, andesites from the Ochils, and other rocks that may well have been derived from the areas

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around the head waters of the Forth, are, as might be expected, by no means rare.

As is usually the case with the maritime boulder clays occurring below the level of the Forth, the surface of that at Leith is locally encumbered with large blocks, which occur, sporadically, between the boulder clay proper and the base of the recent sands above. These are probably due to the scouring action of the river water upon the boulder clay when it happened to form the surface deposit at the bottom of the Forth. The clay has been slowly washed away and the larger stones left behind, exactly as occurs in exposures of boulder clay on the shore now, as, for example, between Leith and Portobello. Those who are inclined to regard the boulder clay at Leith as a true till deposited directly from land ice will perhaps be disposed to explain the presence of some of these surface boulders as due to the action of floating ice after the formation of the till, properly so called, had ceased, and to refer to them as evidence of submergence.

No trace whatever of any form of life could be detected in the boulder clay at Leith—perhaps for the reason given by Mr Peach when this paper was read, that the water in which the boulder clay was dropped was too muddy and perhaps too cold to be congenial to most forms of life.

As regards the origin of the boulder clay under notice, it is not easy to express any definite opinion which would be generally recognised as of value. Were it not for the presence in this clay of stones which seem to me necessarily to have been derived from sources at a distance from any part of Scotland traversed by the Forth branch of the Ice Sheet, I should certainly have been disposed to regard that at Leith as simply an englacial deposit representing the mud, silt, and stones, melted out of the stony and dirty ice, in direct contact with the ground upon which the boulder clay now lies. But, after all, there could not be much difference of importance between a deposit of stones and mud resulting from the melting of dirty ice which was floating in a few fathoms of water and the till which was sedimented from land ice of the same kind directly upon the surface of the rock. I am certainly inclined to regard the former as having been the cause in the present instance, because that explanation will permit of our accounting for the occurrence in the boulder clay of stones that have come *up* the Forth, and are associated with others (the great majority) which have come down that river valley.

If the Leith boulder clay be regarded as due to the liberation

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of stones and mud from floating ice after the climax of the Glacial Period had passed, and the land was standing at a level lower by a hundred or two hundred feet than it has at present, we can readily understand how rafts of coast ice, drifting southward along the east coast of Scotland, might occasionally stray up the Forth under the influence of the winds or currents, and drop their stony and muddy burdens along with the materials melted out of the ice of local origin. A boulder clay formed under these conditions would thus be simply the deeper-water equivalents of the deposits forming the Hundred Foot beach. These deposits, as is well known, testify by both their contents and the local disturbance their strata have undergone, to the occasional presence near the shore of masses of floating ice, which now and then capsized or foundered with their stony burdens quite close to the shore.

It is not pretended that there is anything novel in these views; on the contrary, they are almost word for word repetitions of what has been many times said by others. But as there is in existence even yet an active body of writers on glacial matters who appear to think that the Scottish school of glacialists do not recognise the fact, that, besides much that is the product of land ice, there are also deposits of glacial origin which have been formed subaqueously, it is as well to raise one's voice once again upon this subject. We need only point to such deposits as those at Elie, Errol, Berwick-on-Tweed, to say nothing of the newer glacial beds of the Clyde Valley, as examples of deposits which are, and always have been, universally recognised as having originated in this manner. The fact that some geologists regard certain other deposits as having originated as the *moraine profonde* of the Ice Sheet, or that the majority of other geologists now regard as sediments, melted *in situ* out of the dirty parts of that ice in contact with the ground, as I suggested in 1874,[1] does not preclude us from recognising the possible subaqueous origin of certain deposits elsewhere (such as parts of the boulder clays of East Anglia), whose structure and composition can be more satisfactorily accounted for on the theory that they were deposited from floating ice during a period of submergence, instead of resembling the till in having had an englacial origin from land ice.

[1] Goodchild, "On Drift," Geol. Mag., November 1874.

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Yours very truly
M. Foster-Heddle

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TRANSACTIONS

OF THE

EDINBURGH GEOLOGICAL SOCIETY.

SESSION 1897-98.

XLVI.—*Dr Heddle and his Geological Work.* By J. G. Goodchild, H.M. Geol. Survey, F.G.S., F.Z.S., Curator of the Collections of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art. (Plate XX.)

(Read 16th December 1897.)

Matthew Forster Heddle was the younger son of Robert Heddle of Melsetter, Hoy, Orkney, where he was born in 1828. His ancestors on both sides were of Scandinavian descent: it was therefore to be expected that some of the most prominent characteristics of the Norsemen should manifest themselves in his person sooner or later in life. It is to the antecedents of his forefathers, quite as much as to the nature of the surroundings amongst which he passed his earlier days, that we may attribute many of the characteristics which distinguished him in later life. From his boyhood he had been accustomed to wander amongst the dangerous precipices and lofty sea-cliffs of his native islands, of which it has been said that "there no man dies, for each one breaks his neck"; and he had, further, been early accustomed to trust himself alone in a small boat, in which he often traversed the wild seas of the Orkneys, or found his way from place to place along the dangerous coast-lines of those parts. Surroundings like these could not fail to leave a strong impress upon the character of any thoughtful and reflective youth; and those who knew Heddle in after-life had no difficulty in tracing the development of many of his characteristics to the influence of these surroundings. It was to these early associations that he owed much of his very strong self-reliance; his readiness, when need

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be, to face danger; his fondness for things mysterious, vast, and impressive; and, lastly, the development of a powerful bodily frame and a strong constitution.

From Orkney he went to school at the Edinburgh Academy. There he seems early to have distinguished himself by his readiness to do battle on behalf of his weaker school-fellows. One or two stories told about him while there show him to have been possessed of considerable self-control, fortitude, and pluck. Some other stories connected with his life at the Academy are told in the well-known "Chronicles of the Canning Club," to which those interested in further details are referred.

After leaving the Academy, Heddle went to Merchiston Castle, where we have records of him in 1842, '43, and '44. While there he stayed with the genial author of "Rab and his Friends," to whose influence Heddle was wont to attribute his tastes for natural science, and much else that was good in the later years of his life. At Merchiston he helped to found a school Natural History Society, whose members energetically worked at the zoology and botany of the neighbourhood. Amongst those who were fellow-members with Heddle were Lauder Lindsay of Perth, Wyville Thomson, Lawson of Dalhousie College, Canada, Howden of Montrose, and others hardly less well known. It was at this stage of his career that he seems to have begun to develop that propensity for collecting which became his most dominant characteristic in after-life. He began, it is said, by collecting shells; and in the end he acquired, by this means, no inconsiderable knowledge of conchology. He also got together the materials for a good herbarium. It was an incident connected with this latter which determined in what direction his collecting instincts should lead him in after-life. It is said that he had one day lent this herbarium to a friend, who, by an unfortunate accident while out driving, dropped the herbarium while he was crossing a stream, whereby the results of several years' work were utterly ruined. Heddle made up his mind, after this untoward accident, to collect no more things which could be so easily destroyed, and then straightway began to collect stones in their stead. The commencement of his geognostical work may be said to have dated from the period when that resolve was made.

About this time he entered as a medical student at the University of Edinburgh, and underwent that course of training which has always constituted one of the very best possible foundations for scientific work of almost any kind. At the conclusion of his medical course, he went to Germany to study chemistry and mineralogy, going first to Clausthal and then to

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Freiburg. Regarding Heddle in after-life as a geognoser, one cannot fail to perceive how the influence of the particular kind of teaching imparted to him at these seats of learning pervades much of what he thought and wrote. He returned to Edinburgh, and graduated as M.D. in 1851, taking as his graduation thesis "The Ores of the Metals."

Soon after taking his medical degree, he commenced practice in Edinburgh, somewhere in the neighbourhood of the Grassmarket. His reminiscences of this part of his life do not appear to have been altogether pleasant, and who that knows the neighbourhood and the people can wonder at that? The dismal and squalid nature of his surroundings, the low intellectual grade of the people amongst whom his lot, for the time being, was cast; the absence of any prospect of obtaining more than the very smallest remuneration for the hard work he had to undergo, all seemed to combine to make him look forward to the time when he might escape from the duties of a profession which was evidently so uncongenial to his natural tastes and inclination. If I may judge from what I saw of Dr Heddle during a few years' fairly close acquaintance with him in the field, in the museum, in the study, and by his bed-side, I should say that Nature may have intended him for any one of many professions. He was pre-eminently adapted to become a first-rate actor; he would have made a clever lawyer; as a mechanician his talents showed themselves equally well; he was, as we all know, eminent as a mineralogist; he proved an excellent geognoser; but, assuredly, he did not possess that particular combination of special gifts and acquirements which leads to success in the medical profession. So Dr Heddle eventually turned his attention from medicine, and for the remainder of his life devoted it to chemistry and geognosy. It is well for the scientific world that he did so, for the line of work that he then elected to adopt eventually led to his becoming one of the foremost mineralogists of his day.

In 1856, soon after the date of this resolve, he chartered a boat and went to Faroe, where he succeeded in obtaining an extensive collection of zeolites from the Tertiary volcanic rocks. By means of the numerous duplicates so obtained, he was enabled to effect advantageous exchanges with other mineralogists, and by this means he formed the nucleus around which gathered his large general collection of minerals.

For several years he acted as assistant to Professor Connell, who held the Chair of Chemistry at the University of St Andrews; and all through Connell's long illness and absence from the Lecture-Room there, Heddle filled his place. When

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the professorship at last became vacant, which was the case in 1862, Dr Heddle succeeded to the post.

Dr Heddle filled the Chair of Chemistry at St Andrews for twenty years. He was very popular with the students for many reasons, but chiefly because he was an admirable lecturer, good at experiments and practical work, and possessing the gift—unfortunately so rare in those who hold such appointments—of inspiring his students with enthusiasm.

In 1880 he was invited by a well-known financier to act as consulting-mineralogist in connection with some gold-mines in South Africa. After taking due precautions as regards possibilities in the future, in which part of the transactions Dr Heddle's turn for matters pertaining to law came into useful prominence, he vacated the Chair at St Andrews, and went to South Africa. But after making a full and proper inspection of the evidence on the ground, he felt himself unable to endorse some of the statements that had been made regarding the enterprise referred to. This step led to his return to Britain, and to some legal proceedings, in which he won his case. It may be mentioned that it was from the annuity which his foresight and legal acumen enabled him to secure from this undertaking, that he drew part of his income in the later years of his life.

Mineralogy formed the chief of Dr Heddle's many pursuits. It was upon this, his favourite science, that nearly all his energy, his time, his thought, and also large sums of money were expended. It is a matter of common knowledge how, in the course of a long and active life, he acquired one of the finest general collections of minerals ever amassed by any one man, and also how, during the same time, he diligently explored nearly every mountain and glen, and almost every part of the coast of Scotland, in search of minerals. With Mr Patrick Dudgeon of Cargen, Mr Harvie-Brown of Dunipace, Mr James Currie, junr., and a few other chosen friends of similar tastes, he visited every locality for minerals which previous observers had recorded, and furthermore, himself added a very large number of new localities to the list of those previously known. These visits resulted in the acquisition of the celebrated "Heddle Collection of Scottish Minerals," the finest local collection in the world. Eventually circumstances led to Dr Heddle and some friends making an arrangement whereby his Collection of Scottish Minerals became the property of the nation. They are now located in the Gallery of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art, where their arrangement was begun by Dr Heddle and is being completed by the writer of this notice.

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Dr Heddle wrote a large number of papers, chiefly on mineralogical subjects. The majority of one section of these appeared in the *Mineralogical Magazine*, under the general title of "The Geognosy and Mineralogy of Scotland." They include, as the title suggests, contributions to the Geology, as well as to the Mineralogy of the Doctor's native land. Another group of contributions was published in the *Transactions of the Royal Society of Edinburgh*, under the general name of "Chapters on the Mineralogy of Scotland." Those who will take the trouble to peruse the above-mentioned papers carefully, will find them full of terse statements, charged with suggestive matter, and embodying many original ideas. Not a few of these appeared before the time when people in general were quite prepared to receive them, and they have consequently (as is usual in such cases) been somewhat extensively appropriated (generally without acknowledgment) by writers whose stock of original ideas has been more limited. For some of these researches Dr Heddle was awarded the Keith Medal of the Royal Society of Edinburgh in 1878. He contributed much to Greg and Lettsom's "British Mineralogy," the whole revision of which, before publication, was entrusted to him, and he wrote the article "Mineralogy" in the ninth edition of the *Encyclopædia Britannica*.

He was one of the founders of the Mineralogical Society of Great Britain and Ireland, and was one of their earliest presidents. He was also at one time President of the Geological Society of Edinburgh, and while holding that office was instrumental in urging upon the Government of the day the importance of instituting a Geological Survey of Scotland. He was also one of the oldest members of the Royal Physical Society, and took an interest in its welfare to the end of his life.

Reference has already been made elsewhere to the fact that, for many years, Dr Heddle had been engaged on a comprehensive work on the "Mineralogy of Scotland," of which the greater part of the manuscript was completed by himself, and of which the illustrations, consisting chiefly of most beautiful and delicately-drawn figures of crystals, to the number of over six hundred, were also nearly all completed by the same skilful hand. This work is being edited and completed by Dr Heddle's old friend, Mr Alexander Thoms, and the writer of this notice, and will shortly be published in the form of two handsome royal octavo volumes, by Mr David Douglas.

Regarding Dr Heddle's personal characteristics, one or two other points call for remark. Allusion has already been made to his strong dramatic instincts, to his histrionic talents, to his fondness for receiving mental impression of things grand,

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mysterious, and vast, as well as to his equally-marked fondness for impressing others with conceptions of the same kind. There must be very few of Dr Heddle's acquaintances who have not been aware of this characteristic of his. It was his power of mimicry, strong sense of the ludicrous, powerful dramatic instincts, and fondness for impressing those around him, which combined to make him one of the grandest story-tellers Scotland has ever known. Give him a few striking facts and a second or two to think over them, and he would found upon these a story which would command the attention and interest of all within hearing. Like Turner with the details of a landscape in his mind, the Doctor would think over and rearrange his facts, adding an artistic touch here, enlarging there, throwing subordinate facts into the background, and embellishing with minor details here and there throughout, until the whole was grouped into a striking and harmonious word-picture. There was a marvellous verisimilitude about some of his stories; so marvellous, in fact, that it occasionally happened that a few shallow-pated listeners accepted the whole story as perfectly true.

Another characteristic of Dr Heddle's calls for remark. All of his acquaintances were fully aware of the fact that, for some few years past, he enjoyed bad health. But so powerful was his interest in his favourite pursuits, that the very mention of them would generally make him forget all his ailments, real and imagined, and he was then able to perform great walking feats, or to climb high mountains, to wield ponderous hammers, or to carry heavy bags of stones, each to an extent which few much younger men could well imitate. The large size of his hammers was very well known to his friends. Even his alpenstock was bigger than anyone else's, and one may truly say of it, as was said of the timber carried by one of the giants of old, that his staff "was like a weaver's beam."

Like most other persons of strongly marked character, the Doctor evinced strong likes and dislikes, and therefore occasionally made enemies. But his dislikes to the persons in question were usually founded upon their having violated some principle, and not upon some motive affecting himself. I cannot recall a single instance of the contrary. In the case of a small number of persons of whose public conduct the Doctor had more or less reason to disapprove, the very mention of their names, even when he was in a state of extreme bodily and mental prostation, acted upon him like the sound of a trumpet-call to an old warhorse, and then those around him had the greatest difficulty in bringing him back to a state of quiet.

For myself, who had much to do with Dr Heddle, I may

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say that, taking him all in all, I looked up to him much as Boswell looked up to Johnson. Like his prototype, he did much original work of good quality, and in the face of many difficulties; like Dr Johnson he never sought honours (so none were conferred on him); like Dr Johnson he never appropriated other men's ideas; and, like Dr Johnson also, he was much given to doing kindly acts, in a quiet way, towards his fellow-men, and looking for no reward. The memory of one of whom we can truly say these things must surely long remain fresh in the minds of men of science.

To the scientific world in general, Dr Heddle was, of course, best known in connection with mineralogy. But no one who has attentively considered his various writings on that branch of science, can fail to perceive that his contributions to geology, especially in his papers on the Geognosy of Scotland, were hardly of less importance than his mineralogical work. In Dr Heddle's student days geology, in the modern sense of the word, may be said hardly to have come into existence; and those who had begun to pursue that branch of science had at first to feel their way very much in the dark. Most of the earlier work on the continent and in Scotland had to do chiefly with the materials of the earth's surface, and was very little concerned with any deductions that might be drawn from the study of those materials regarding either their relations to the history of the earth in the past, or to its architectural features of the earth at present. Geognosy, indeed, may be justly regarded as a sister science to Mineralogy, and as the parent of the modern sciences of Chemical Geology and Petrography. It is largely owing to the researches of the pioneers in this branch of geology that much of our present knowledge is due.

Dr Heddle may be said to have had two principal objects in going into the field: firstly, to collect great quantities of the largest and finest specimens of Scottish minerals with his own hands; and secondly, to gratify his fondness for things vast, grand, and impressive, and for doing what other men had attempted to do and had failed.

These motives led Dr Heddle to explore almost every known Scottish locality for minerals, and, in doing so, often to climb where it was dangerous, or to land where few else would venture, or to risk having to pass the night on moors remote from any human habitation. This, too, at a time when there were no Ordnance maps in existence, and few others upon which very much reliance could be placed. We are apt to forget about these matters in these days of easy travelling,

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when first-rate maps are to be had, and housing accommodation can always be counted upon.

Thus it came about that Dr Heddle, while regarding nearly all geological questions from the standpoint of the chemist, yet did a large amount of field-work. If any proof were required of this, one need only refer to the geological maps of Orkney, Shetland, and Sutherland in his Geognosy of Scotland. In addition to these important published contributions to the Geology of Scotland, Dr Heddle had for many years been engaged upon a geological map of Aberdeen, Elgin, Nairn and Banff, and some of the adjoining parts of Inverness, which he never completed. When it is considered how little was actually known regarding the geological structure of large parts of these areas, it must be matter for wonder how any one man, working single-handed, bearing his own expenses, and hampered by having to work with unreliable maps, and by the innumerable difficulties presented by both the nature of the ground and the complicated structures of the rocks, could accomplish so much in a single lifetime. If, of this part of Dr Heddle's work, it has happened, in a few cases, that fuller investigations had led to different interpretations of the facts, all must admit that, like MacCulloch, Nicol, Hay Cunningham, and others, he helped very materially to lay the foundations of our present knowledge of the Geology of Scotland; and, like other early workers, he often made statements and recorded facts which were questioned for a time, then accepted, and, ultimately, credited to later writers.

Amongst what we may term Dr Heddle's minor contributions to geology, special attention may be called to his observations on the nature of pegmatites. Dr Heddle devoted very considerable attention to these interesting forms of crystalline rock, and much that he wrote about them, being based entirely upon his extensive and close observation in the field, is both suggestive and valuable, and contained ideas which were very far in advance of the general knowledge of the time at which he wrote; and it is perhaps hardly going beyond the mark, to state that Dr Heddle's views regarding pegmatites are, even yet, ahead of any others.

Upon another point of geological importance he was the first to pronounce with decision. Normal granite consists of a holocrystalline compound, with granitic structure, of *quartz and potash felspar*, with, or without, other constituents. Dr Heddle pointed out, in his "Chapters on the Mineralogy of Scotland," when referring especially to the grey granite of Aberdeenshire, that the dominant felspar in this granite was not Orthoclase, nor a potash felspar of any kind, but the soda-lime felspar

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Oligoclase. Subsequent investigation has abundantly proved the truth of this statement, and, furthermore, has shown that it is true also of the great majority of Scottish granites. He was also the first to point out the relative abundance of Microcline, especially in Scottish pegmatites, in which the felspars are usually Oligoclase together with this form of potash felspar. A further generalisation of Dr Heddle's with regard to the felspars, was the comparative rarity of Albite in Scottish rocks, and the abundance and wide diffusion amongst the sub-basic and basic erupture rocks of Labradorite. All these generalisation are geological points of considerable importance.

Then, with regard to the micas, he has shown that of the dark micas the commonest in both the erupture and the gneissose rocks of Scotland is Haughtonite, while Biotite proper is almost confined to thermo-metamorphosed limestones.

Another of Dr Heddle's generalisations, which has important geological bearings, relates to the specific heat of colloid substances as compared with that which the same substances have when in the crystalline condition. Applying the principle to limestones, he pointed out that in the change from the amorphous, or original form, to the crystalline form which they subsequently assume under particular conditions, a quantity of heat equivalent to the difference between the specific heat in the amorphous and that in the crystalline condition has been liberated. He stated his belief that the heat thus disengaged was sufficient to produce very important modifications upon the surrounding rocks. In the Gallery of Scottish Geology and Mineralogy in the Edinburgh Museum of Science and Art, he has displayed specimens of his own collecting which he believed bore out this principle very fully.

Another point related to the last, and also of importance in connection with rocks of metamorphic origin, upon which he often spoke (but the present writer is not aware that he ever published it), relates to the fact that, when rocks are affected by dynamic action, part of the energy of motion, as is well known, is converted into the energy of heat; but that if the dynamic cause operates a second time, after the heat has been so disengaged, the rock simply breaks up, with little or no disengagement of heat. He believed that one of the chief effects of the dynamic action was to develop a crystalline structure in rocks that had been previously amorphous, and that the heat liberated was chiefly that due to the difference in the specific heat in the two states. [Dr Heddle's conclusion might be pushed further and applied to explain the development of granulitic structure in dynamically metamorphosed rocks, which structure would thus appear to be due to the effects

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of a second movement after the crystalline stage had been developed, provided that these rocks had not in the meantime been exposed to heat from outside sources, or, in other words, annealed.—J. G. G.]

In another of Dr Heddle's unpublished statements, he expounded some of the laws that govern the rounding of grains of sand.[1] In this some important and valuable suggestions were made, some of which the present writer has adopted (with acknowledgment) and extended, in a paper read before the Edinburgh Geological Society on "Desert Conditions in Britain."

Along another line of enquiry Dr Heddle had worked for many years. This was in connection with the origin and structure of agates—a subject which he may be said to have made almost peculiarly his own. Many of the conclusions possess an interest chiefly for the physicist; but amongst those which are of interest to the geologist may be mentioned his remarks upon the formation of the onyx bands in agates. These, he has shown, were deposited within the agate in an absolutely horizontal position, and at an early stage in the history of the rocks in which they occur, and almost invariably before any disturbance affected those rocks. [Any inclination these onyx bands may now possess is therefore a measure of dip of the rocks, and is, perhaps, the only means we possess of measuring the angle through which a lava has been moved subsequently to its consolidation.—J. G. G.]

Dr Heddle specially prided himself upon his contributions to the history of dolomitisation of limestones. He was one of the first to show that in the conversion of a normal limestone into dolomite a certain easily-estimated diminution of volume took place, which, as he and others have pointed out, has led to the formation of a carious structure in the rock, and to the development of the well-known geodes that characterise limestones which have been converted into dolomite.

Lastly, reference may be made to the germs of another principle of geological importance of which the present writer has heard Dr Heddle speak. The Swiss geologists, from the early days of Agassiz downwards, have recognised that the sun's rays falling upon ice or snow do not raise the temperature of the ice or the snow so much as they do that of foreign bodies that may happen to lie below the surface. Professor Tyndall has also made reference to the same principle. Dr Heddle used to say that it was this cause which made dirt and stones on the surface of the ground beneath snow tend to melt their way upward towards the surface. [The present writer has

[1] Lecture on "Sand" given before the Edinburgh Field Naturalists.

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extended this principle, and applied it to explain the uplift of stones within the Great Ice sheet, and therefore to the elevation of boulders to positions higher than that of their sources.]

The limits of this notice forbid fuller reference to Dr Heddle's contributions to geology; but enough has been presented here to justify the statement made at the head of this section, and to which the present writer is disposed firmly to hold, that Dr Heddle's geological work is nearly equal in importance to his contributions to mineralogy.

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XLVII.—*The Minerals of the Storr.* By Professor M. F. Heddle, M.D., F.R.S.E.

[The following paper is a portion—somewhat abridged in part—of a paper read by Dr Heddle before the Geological Society of Edinburgh on 6th March 1856. No corrections or additions have been made, but in order that it may be more useful the crystallographic symbols are given as in Dana's Mineralogy (6th Edition). The Society did not at that time issue Transactions, and the paper was therefore never printed. As no mineralogical description of the locality has since been published, the account will be read with interest even after this lapse of over forty years.]

The hill, or to speak more correctly the huge pillar, called the Storr is about ten miles north of Portree. In favourable weather it is most easily reached by taking a boat from Portree to a point about eight miles to the north. Landing here near the foot of a lofty cascade and surmounting a steep ascent of 1800 feet, we find ourselves in a vast amphitheatre resembling the crater of an extinct volcano, closed in behind by a dark and beetling cliff, while the view seaward is almost shut out by huge columns, rising in one instance to a height of over 150 feet.

It is from among the debris which is constantly falling from these pillars, or by the laborious breaking up of the larger and more solid masses which are more rarely loosened from the cliff, that the mineral specimens are obtained.

We approach the Storr from the south-east by keeping alongside of a wall which leads us to a cliff at the foot of which is a large quantity of debris containing the finest specimens of *Gyrolite* to be found at the Storr. The rock being a tough basalt, good specimens are only to be obtained by blasting.

Ascending a steep grassy slope, we next come to masses of amygdaloid fallen from two pillars which form a sort of gateway to the amphitheatre above. Here the following minerals are to be obtained:—

Mesolé or *Faroelite*, coating the cavities with mammillations and with spheres which are sometimes almost complete. The specimens from this locality are the finest to be obtained in the British Islands and almost rival the Faroe specimens.

Apophyllite, in small crystals superimposed on the Faroelite, and not so fine as at the next locality.

Stilbite, occurring similarly.

Mesolite, in delicate feathery tufts, occupying cavities by itself.

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Following a sheep-track northward among the pillars, we pass a spring, and between the four larger pillars and the cliff come upon an enormous quantity of fallen rock which, about 1845, was hurled from the precipice by the splitting action of freezing water. The noise of the fall was heard at Portree. This may be considered perhaps the finest zeolite locality in Britain, as it yields eleven different species. These arranged according to the frequency of their occurrence are :—

Chabazite.—Nearly every cavity of the amygdaloidal rock is lined with minute highly polished crystals of this mineral in the primary form *r*. It also occurs rarely in the combination *ts* and in minute twins of *rs* and *res*. A fifth form seems sometimes to be present, but I have convinced myself by the examination of many crystals that this is nothing more than an oscillation between the faces *t* and *r*.

Apophyllite occurs in specimens of great beauty, the crystals sometimes attaining the length of 2 inches with a breadth of 1 inch, and exhibiting, by polarised light, in great perfection, the structure from which the species obtained from Brewster the name of Tesselite. The combinations here are *ac, arc, apc, apcr.*

Stilbite.—The specimens found here vary very much in appearance. At one spot they occur associated with Laumontite in the large sheafy conglomerations of crystals found so generally in Iceland and Faroe. At another spot they are in isolated and highly perfect forms; while at a third the crystals are grouped like a fan, the crossing of different individuals of this variety forming spheres resembling those so common in our Scottish Prehnites. The forms of Stilbite to be seen here are *bcf, bcfm, bcm*, and twins of *bcm.*

Laumontite is here found in veins about 1 inch in thickness, which consist of a congeries of minute crystals so confused as to present a granular appearance. This mineral, strange to say, used to pass under the name of Hypostilbite, and under that name came into the hands of Dr Scott, who analysed it. So large a mass of this Laumontite is attached to the cliff that I have been able to distinguish the white spot from the Sound of Scalpay, some twenty miles away.

Gyrolite occurs here in great abundance, generally associated with Apophyllite. It is further found *per se* at the east side of the foot of the great pillar, and also at a spot a little south of this. Unweathered specimens of this mineral are rare, as it seems to lose water as readily as Laumontite; and on account of the foliæ flying asunder at the slightest shock, fine specimens are obtained with considerable difficulty.

Sphærostilbite.—The mineral so named by Beudant occurs here

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in minute spheres. I was not successful in obtaining a quantity sufficient for analysis; but when viewed under a microscope the mineral so much resembles Stilbite that I have little doubt of their identity.

Analcime is rarely found in small but brilliant crystals of the usual form.

Mesolite occurs as at the last locality in delicate acicular crystals.

Faroelite does not occur at this locality in specimens so fine as those last mentioned, but it lines all cavities which do not contain *Chabazite*, which seems to supply its place.

Steatite [Saponite] of a pure white and of a pale green colour fills up the smaller nests and lines larger cavities.

Calcite, here an unusual mineral, occurs in minute rhombs and sharply acuminated prisms.

Heulandite occurs in colourless crystals, the lustre of which is quite equal to that of the Icelandic specimens, but which do not exceed, so far as I have seen, ½ inch across the face *b*. The following combinations occur: *cstmb*, *cstbmx*, *cstmbu*, *cstmbux*.

Levyne is rarely found here, as usual twinned in the form *crs*. Specimens obtained from Mr Doran of the form *rs* are doubtless also from this locality. It is the sole occupant of the druses in which it occurs.

The *Plynthite* of Thomson occurs in veins which intersect the columns.

The lower portion of the cavities is sometimes occupied by *Onyx*, formed of alternate layers of bluish Chalcedony and milk white Cachalong.

Hardly a cavity can be opened that does not contain water. Some of those about the capacity of a thimble are full of it, containing nothing else except a mere film of Faroelite. Others again, which appear to be quite filled with needle Mesolite, pour out water when the finger is thrust into them. The Steatite [Saponite] also, when first taken from the cavities, contains so much water as to have the consistence of butter. This zeolitic water has a slightly alkaline taste, and a small quantity evaporated on a watch-glass left a film of a gritty powder which did not scratch the glass.

It is worthy of notice that some of these minerals—such as Analcime, Chabazite and Apophyllite—are found sometimes loose without attachment in the cavities, of course crystallised all round, or suspended on a microscopic needle of Mesolite. The Apophyllite, Analcime, Chabazite and Gyrolite are, when the cavities are first broken into, so devoid of colour and so perfectly transparent that were it not for the reflection of light from their faces they would be absolutely invisible. Apophyl-

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lite and Gyrolite have, when fresh, not a trace of pearly or fish-eye lustre, such being consequent upon a loss of water. In Heulandite and Stilbite again the lustre is inherent, and the loss of water causes them to become chalky in appearance.

In the return from the Storr a point on the summit of the cliff almost directly above Prince Charles's Cave should be visited, as it affords *Pectolite* of a delicate bluish-green colour, not elsewhere equalled. I am indebted for this locality to Mr Doran, who supplied the specimens analysed by Dr Scott, by whom, however, the Storr was erroneously given as the locality.

Inferior specimens of many of the zeolitic minerals may be obtained at almost every spot in the neighbourhood of Portree, at which the trap is exposed in cliffs or broken open as quarries. The nearest locality, however, worthy of notice is at Rudha na h-Airde Glaise on the shore two miles north of Portree. Here a considerable amount of debris has accumulated from which may be obtained indifferent specimens of *Gyrolite*, *Apophyllite* and *Mesolite*. These three minerals sometimes occur together in a cavity. When this is the case the Mesolite is invariably next the rock, and covered in turn by Gyrolite, the Apophyllite filling up the centre of the nest. In some instances the Mesolite is wanting: in others the Apophyllite is absent: frequently the Mesolite occurs alone. In all cases, however, when more than one is present the order or superposition is as noted.

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XLVIII. *The Subdivisions of the Carboniferous Series in Great Britain and some of their European Equivalents.* By Wheelton Hind, M.D., B.S.Lond., F.R.C.S., F.G.S.

(Read 20th January 1898.)

It is a well recognised fact "that the sequence of the Carboniferous series of beds, as found in Scotland, differs essentially from that which obtains in central England," and the correlation of the two groups has been attended with difficulty, mainly due, as I have pointed out in the *Geological Magazine* for April and May 1897, to a misconception of the succession of carboniferous rocks in Yorkshire, and to the fact that Professor Phillips established a purely local succession as typical of the carboniferous sequence in central England. The main evil which has resulted from this classification, is that in other districts where the succession is totally different, an altogether artificial and arbitrary set of divisions has been made, which can neither be followed in the field nor identified by palæontological evidence, so as to bring it into line with the so-called typical section. Several systems have been proposed for the classification of the carboniferous rocks, all more or less based on lithological characters, for, up to the present, little or nothing has been accomplished in establishing life zones for the carboniferous rocks of Great Britain; but the great mistake in all of them is the establishment of the millstone grit and Yoredale series as essential subdivisions, and the attempt to make artificial equivalents for them in Scotland and Ireland, where the succession of rocks is often entirely different from that which obtains in central England. Would the terms millstone grit and Yoredale series ever have arisen if the carboniferous succession in Scotland had been chosen as the type? I would emphatically protest that these so-called subdivisions are only extremely local conditions, and due to local causes, which probably were not acting in other districts, and I propose to show that such is the case by tracing the sequence of the carboniferous beds from Derbyshire to Scotland and noting the gradual series of changes which they undergo in passing from the English to the Scotch type of succession.

In Derbyshire we have not yet been able to reach the base of the carboniferous limestone, which exists as practically one mass, for though composed of various beds—crinoidal, detrital,

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siliceous, organic—the limestone is not divided up, as in Scotland, into beds by masses of shales; and we only find thin partings of 1 to 6 inches at rare intervals.

Lower Limestone Shale, Basement Beds, etc.—Although not exposed, we have every reason to believe that beds of Carboniferous age may exist below the limestone, for such a bed is known to be 660 feet thick in the Avon section, near Bristol, and in North Wales the basement beds, consisting of bastard limestone, conglomerates, and shales, etc., with pebbles containing Silurian fossils, reach about 500 feet. In the Pennine area, the basement beds are only exposed at the foot of Ingleboro, in King's dale and Ribblesdale. Here the beds are very thin and patchy, resting unconformably on the upturned edges of Silurian slates, and at Thornton Force only attain to about 5 feet in thickness. Here the beds consist of a brecciated conglomerate with quartz pebbles and rolled Silurian rocks and occasional carboniferous corals. Further north, Mr Goodchild has described the basement beds in Hebblethwaite gill; and these are succeeded by about 130 feet of shales and impure limestones which occur immediately below the great Scar limestone. The following section of these beds is given by the Geological Survey (*Mem. Geol.*, Mallerstang, p. 50):—

		Feet.
Lower limestone shales and basement beds.	Grey calcareous sandstone with green partings and white nodules	40
	Red and green shale with hard sandy bands and numerous concretionary white nodules at the top	12
	Purple and white mottled sandstone	3-4
	Red conglomerate	3
	Red sandstone	2-4
	Red conglomerate	20
	Conglomeratic grey and purple sandstones with bands of red conglomerate interstratified	17
	Red conglomerate of Hebblethwaite gill estimated at about	900

Some of these beds are seen again in Ravenstonedale, but the basement conglomerates are not seen and are probably absent.

In the neighbourhood of Ash Fell and Roman Fell, Mr Goodchild has drawn attention to the presence of an interesting series of sandstones with plant remains, limestones of tolerable thickness, conglomerates and shales which is developed below the great Scar limestone. Further north still this series

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expands into the Tuedian beds of Northumberland, which are subdivided by the officers of the Geological Survey into lower freestones, cement limestones, and an upper set of Fell sandstones. The lower group, also consisting of two divisions, thus:—

Upper or cement stone group.	{	With freestones, dark-grey and greenish shales with impure bands of limestone and cement stone.
Lower. Freestone group.	{	Freestones with purple, lilac, green and red shales.

At the base of the latter occurs occasionally a pebbly basement bed, and in some places a conglomerate.

The upper division or Fell sandstones consist of thick beds of quartzose sandstone of various colours with beds of shale, sometimes marine.

The fauna of the Tuedian beds is largely non-marine, and is characterised by the presence of *Modiola Macadamii*, but it differs markedly from the fauna in the beds above, called *The Carboniferous Limestone Series*, which contains *Productus giganteus* at several horizons, a fossil never found in the Tuedian or calciferous sandstone series. I regard these Tuedian beds as the Homotaxial representatives of the basement beds of Ingleboro and the Calciferous Sandstone Series of Scotland. In the field there is abundant evidence that deposits which are the results of land denudation increase in thickness and importance as they pass northwards, where there is no doubt the continent existed whence they were derived. On the Fifeshire coast Mr Kirkby has shown that these beds contain occasional marine bands, and if the fauna of the bands and that which the officers of the Survey have found in the Tuedian beds be compared they will be found to be very similar.

Carboniferous Limestone Series.—In the Mendips, Derbyshire, and the south of Yorkshire the Carboniferous Limestone is in one mass, made up, it is true, of various beds, encrinital, detrital, etc., but the beds are not separated from each other by any extent of shales. Occasionally in Derbyshire thin partings may occur which rarely attain a thickness of 6 inches.

Between Castleton in Derbyshire and Clitheroe in S.E. Lancashire the limestone is not exposed, but as far north as this, it still maintains the same massive structure as further south. The uppermost beds in Derbyshire are highly fossiliferous and are largely made up of well rolled shells and fossil fragments, with pebbles of hard limestone and an occasional one of white quartz. This bed was evidently laid down between tidal limits and I have been able to trace it for miles across country, always

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at the same horizon, where it marks the line of a retreating sea-beach.

This condition of things also occurs in the neighbourhood of Grassington at Hill Bolton and the series of several dome-shaped limestone hills, a characteristic form of weathering both in Yorkshire and Derbyshire, but here the shells afford less evidence of rolling. It was these dome-shaped hills and the shell beds in them which were remarked upon by Mr Tiddeman in a paper read before the British Association, 1890, and published at p. 600 of the Report. He speaks of the hills "as suggestive of the idea of reef-knowls," which he speaks of as "growing up on a slowly sinking sea bottom"; and goes on to say: "Moreover, at the foot of these mounds or reef-knowls, as I would call them, we have in many places a breccia formed of fragments of the limestone, which, I take it, have been broken off the reef between wind and water and have subsequently been covered up by the mud of the Bowland shales and compacted into a breccia." Now in the first place there are no reef building Corals in the Carboniferous Rocks and no other organism which is capable of constructing reefs, so that this theory falls to the ground at once; but further, the peculiar conformation of the country at that place is due to the natural weathering of a rock soluble in water, and the same shaped knolls of weathered limestone occur frequently in Derbyshire, N. Staffordshire, the Isle of Man, and notably in the upper beds of limestone north of Malham Cove.

In fact, the breccia of limestone and rolled fragments is the contemporaneous beach which occurs, just as it does in Derbyshire, at the top of the limestone, and is overlaid by the Bowland shales. Of all the wild speculations of geologists, this, I think, is based on as little actual fact as any, and Mr Tiddeman cuts the ground from beneath his feet when he adds as a postcript: "In speaking of the mounds as knowl-reefs, I do not necessarily wish to imply that they were coral reefs. They seem to have been built up in a somewhat similar way, but corals apparently only played a subordinate part in their formation." One would have thought that it was necessary to have found a reef-building organism of some kind before venturing to suggest such an hypothesis.

As in Derbyshire, the beds below the beach at Hill Bolton are grey crystalline limestones without much apparent bedding, but were certainly not laid down under aerial conditions of any kind. The beds are crammed with Brachiopods in beautiful condition, and many fine Cephalopoda, Gasteropoda and Lamellibranchs, the latter chiefly byssiferous, indicating shallow water, are found, but corals are conspicuously absent.

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The massif of limestone continues unbroken till about ten miles north of the great East and West Craven fault, about which locality a tendency is observed for the upper part of the limestone to split up into beds of varying thickness by the intercalation of beds of shale, thin at first, but which increase in number and thickness as the beds pass north. Mr Tiddeman considered that the change in type of the carboniferous rocks in the north and south of Yorkshire was due to some occult effects of a contemporaneous system of faulting, but the change does not begin to take place until some miles north of the faults. At Hebden, near Grassington, we notice one bed of limestone completely separated from the main mass by a bed of shales. Tracing the beds further north up the valley of the Wharf, on the flanks of Whernside, Buckden Pikes, and the other hills, we find that an increasing number of limestones form features on the hills, intervening between the beds of millstone grit which cap them and the massive of limestone below till we pass into Wensleydale where the limestones are so well marked as to receive individual names, and the intervening beds of shale are much increased in thickness, thick beds of sandstone also coming on with the shales. While this series of alternating limestones, sandstones and shales measure 1500 feet, the main mass of limestone, now called the Great Scar Limestone, has dwindled to 600 feet, so that in actual vertical thickness it barely reaches the equivalent of the 2000 and more of the Carboniferous Limestone of Derbyshire. There is no doubt that Professor Phillips fully recognised this fact, for he states (*Geol. Yorks.*, pt. ii. p. 32): "The great limestone series which at Greenhow Hill is one mass, admits between some of its upper members partings which are thin at Grassington and Kettlewell, but towards the N., N.W., and N., augment in thickness and assume new characters." It was to this series of beds, as developed in Wensleydale, that Professor Phillips gave the name Yoredale series, and he took as the base line the Hardraw scar limestone, which is the bed of limestone in this locality which succeeds the great Scar limestone, separated from it by a varying quantity of shales and sandstones. But unfortunately this base is not constant, for further south it coalesces with the great Scar limestone (*Geol. Surv. Mem.*, Country round Mallerstang, p. 9), and in the Ingleboro area occasional limestones intervene between them. Further, if the great Scar limestone itself be traced north, it splits up itself and is separated into distinct beds by wedges of shale and sandstone and forms the Melmerby scar series, so that although only about ten distinct limestones are recognised in Wensleydale, by the time the beds arrive at Alston Moor there are

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twelve limestones, and further north, in Northumberland, Westgarth Forster recognised nineteen, but it is doubtful whether these all belong to the Carboniferous limestone series. In Northumberland, above the Fell sandstones, succeed a series of rocks, called by the officers of the Geological Survey the Carboniferous limestone series, which are divided by them into two divisions:

A lower or Carbonaceous division;
An upper or Calcareous division.

But the fauna of the two series is wonderfully alike, by far the larger number of the fossil species being common to the two divisions. I regard the whole of this series as the equivalents of the Carboniferous limestone of Derbyshire, and the great Scar limestone and Yoredale series of Wensleydale. But there seems to be some uncertainty as to such a correlation in the mind of the Director-General of the Geological Survey, for, in the preface to the Survey Memoir on Norham and Tweedmouth, dated April 6th, 1897, Sir A. Geikie says:—"The geology of this area is extremely simple, the rocks consisting entirely of stratified formations belonging to the Carboniferous limestone Series, and chiefly to that portion of the series represented by the Scar limestone of Yorkshire." This may be so, but what represents the Scar limestone in Derbyshire, or in North Durham? Surely it only adds to the difficulties of correlation to take the local expression of a very changeable bed as a type, a bed, too, which is not able to be defined for more than a few miles, in either its upper or lower limit, and which is not marked out by a special fauna. But further, on the 8th July 1897, Sir A. Geikie writes in the preface to the Survey Memoir on Berwick-on-Tweed: "Under the whole of the district various members of the Carboniferous limestone series extend, the thicker limestones being representatives of the Yoredale series of Yorkshire"; but on turning to the table of contents we find the same series of rocks as described in the former Memoir. In the Berwick Memoir, p. 30, it is stated that *Productus giganteus* occurs in limestone intermediate between the Woodend and the Oxford limestones, and as I shall show later on that this fossil is characteristic of the great Scar and all the Yoredale limestones. Some of the limestones disappear as they pass north, dying out, but it is impossible to say whether it is the upper or lower beds which have died out first. And further north, in Scotland, is the extensive sequence known as the Carboniferous Limestone series, subdivided into an *upper marine series* with several beds of limestone separated by shales, a *middle estuarine or fresh water series* with coal and ironstones but no limestones, and a *lower marine series* with several beds

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of limestone. *Productus giganteus* characterises both the upper and lower divisions, but is of course absent in the middle group, and corals are far more common in the lower division than in the upper.

It has been supposed that these three divisions are the equivalents of the Yoredale rocks of England (*B. N. Peach. Ref. Internat. Geol. Cong.*, 1888, p. 157), and that the Calciferous sandstone series are the equivalent of the Carboniferous limestone of England, but if there is any real value in palæontology as a factor in correlation, the evidence conclusively shows that the fauna of the Carboniferous limestone and the Yoredale series of the Wensleydale area are identical, and that this fauna is largely that of the upper and lower divisions of the Carboniferous Limestone series of Scotland: the essential differences being due to the fact that the Scottish beds were laid down nearer land and the fauna has a larger number of sublittoral forms than obtains further south.

The Yoredale series, therefore, is only a local phase of the Carboniferous limestone and cannot in any sense be regarded as superimposed upon it or as forming an essential subdivision. So also the Carboniferous Limestone series of Scotland is really the equivalent of the whole "massif" of limestone of Derbyshire, the Great Scar and Yoredale series of Wensleydale and the division of rocks in Northumberland called the carbonaceous and calcareous divisions by the Officers of the Geological Survey. Not only is this the case on lithological grounds but it is amply borne out by palæontological evidence which I shall briefly review just now.

Bowland Shales.—Above the "massif" of limestone in Derbyshire and South Yorkshire occurs a series of black shales with occasional gannister-like sandstones and thin beds of concretionary limestones, which the Officers of the Geological Survey, following Phillips, have unfortunately mapped as Yoredale rocks. They have nothing in common with the rocks of Wensleydale either lithologically or palæontologically. They have a very local distribution and are really at a higher horizon than the Yoredale series. The Officers of the Geological Survey estimate the thickness of these beds in Derbyshire and North Staffordshire as between 2000 and 3000 feet, but it really is nothing of the sort. Wherever a direct sequence of the series is to be obtained actual measurement gives not more than one-third this amount, and the mistake has arisen through the repetitions of the same beds by a series of anticlinals and synclinals, the rocks, however, altering in lithological characters and thickness, so that the repeated beds were not recognised as the same in localities some few miles apart. This subject I am now working out in

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detail, and hope to publish shortly, in conjunction with Mr J. A. Howe, a paper giving measured sections to prove my contention. Occasionally a few thin bedded limestones form a series of passage beds between the limestone and shales. This series of beds is exposed in the bottoms of the valleys near Marsden, and further north at Todmorden and Hebdenbridge, and yield a fine series of characteristic fossils similar to those found in the same series further south.

A fine sequence of the beds which succeed the massive limestone is seen at Pendle Hill, the crest of which is formed by Farey's grit, once called the Yoredale grit, but afterwards classed with the millstone grits by the Survey. Here, it is estimated, the following succession occurs:—

Pendle grit.	Upper	1000 feet.
	Shales. Bowland shales	200 „
	Lower. Very inconstant	? 600 „
Pendle side limestone series		350 „
Shales with limestones		2500 „

I cannot but think that this estimate is too great; for there does not appear to me to be room for this amount between Worsae End and Hook Cliff. The sequence is well exposed in the beds of streams and cloughs on the flank of the hill, and the beds in every way resemble those of Derbyshire and North Staffordshire palæontologically and lithologically. On the whole, the limestones in the series are thicker, and more siliceous. The Pendleside limestone is no doubt the equivalent of the thin limestones of Onecote, Morredge, and the Dane valley of North Staffordshire and Derbyshire.

In my former paper "On the Yoredale Series" (*Geological Magazine*, 1897, p. 162), I made a stupid blunder, due to a too implicit trust in the palæontological table at the end of the Geological Survey Memoir of the Burnley coal field. I have since that time been over the whole of the ground in this district and visited with Mr J. A. Howe the fossiliferous localities named in the memoir, and we are thoroughly convinced that the Pendleside limestones have a totally different fauna from that of the mass of limestone below it, but typical of similar beds in other localities. The mistake arose mainly from the inclusion of the Asnot-inlier as a portion of the Pendleside limestone. I carefully examined this and am convinced, on account of the palæontology of its beds, that it is a portion of the main mass of limestone faulted up. As Mr Tiddeman observes in the memoir, the lithological character is that of the Carboniferous Limestone. On the West, this limestone dips regularly to the North-West at about 30°, and at the foot of the hill in the

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stream, the equivalents of the Pendleside limestones are to be seen in a fine section dipping West at about 25°. This series on West flank Pendle contains *Posidoniella laevis* and Goniatites, with near the top a bed of encrinital limestone. Petrologically the limestones of this group are perfectly distinct from any found in the massive of Carboniferous limestone, being dark, hard, with conchoidal fracture and possessing a strong smell.

The Pendle limestones and grits appear to have a great local development which rapidly diminishes, so that a few miles away they are much diminished in thickness or are absent altogether.

At Longridge, a few miles South-West of Clitheroe, the Pendle grit thickens out considerably, and there is a fine section of the beds in the quarry.

To the North-West the shales, however, rapidly diminish in thickness, so that at the Sykes and Brennan anticlinals the millstone grits appear to be separated from the limestone by a much smaller series of beds than on Pendle Hill. Further in this direction, at Carnforth, the Pendle side grits vanish and the shales below them are still further reduced in thickness. In a northerly direction, too, a few miles from Skipton, these beds thin out rapidly, and though present at Burnsall fell and Flasby, where the characteristic fossils can be obtained, are only about 30 feet thick, and in Niddale become reduced to about 20 feet. North of this, these shales gradually disappear, so that the millstone grits succeed the Yoredale series of Ingleboro and Wensleydale directly, being, on Ingleboro, separated from the main limestone by only 120 feet of shales, which, however, do not contain the typical fossils of the series. Fuller details are given in my paper on the Yoredale series, but further north I have been able to obtain no fossil evidence that these shales exist and there is little or no doubt that the millstone grit beds overlap them in a northerly direction. This series of shales are therefore really at a higher horizon than the Yoredale beds and must no longer have this term applied to them. I therefore think it advisable to apply Phillip's term, Bowland Shales, to this series of beds, which have a distinctly different marine fauna from the beds below them—a fauna, however, not confined to these beds, but which passes upwards through the millstone grit beds, where it occasionally reappears in the shales which separate the several grits, and reappears in force in the Gannister beds of the Lower Coal Measures, which is apparently its upper limit, but it only, of course, is present in the beds which were deposited under marine conditions and does not occur in those of fresh water or estuarine

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origin which are very extensive in this series of rocks. A similar flora, however, is characteristic of the Bowland shales, grits and gannister series.

Phillips apparently applied the term *Bowland Shales* to those beds which occur between the Kinderscout and the Pendle grits. I now propose to include under the same term the series of beds containing practically an identical fauna, which intervene between the Pendle grits and the mass of Limestone, or if this term be thought to be unsuitable, that of *Posidoniella Shales* would be useful from a palæontological point of view, characterising the beds by the typical fossil of the series.

The Millstone Grit Series succeeds the Bowland Shales in Derbyshire, South-East Lancashire, and South-West Yorkshire, and have their greatest development in the latter area. The series consists of several thick beds of quartzose and pebbly grits, nearly all of fresh water origin, separated by beds of shale, but neither lithologically or palæontologically are they marked off from the Bowland shales below them or the coal measures above. To the South, the beds thin out rapidly and diminish considerably in thickness, only two beds, the first and third grits, being found at Mow Cop, North Staffordshire, where they only attain a thickness of about 200 feet. To the North of Wensleydale also the Millstone Grit beds diminish in number and thickness, until it is very doubtful whether any true equivalents of the millstone grit rocks are to be found north of the south part of Northumberland. In Scotland certain sandstones are said to represent this series, but I am certain that had not the Millstone Grit been accepted as one of the main subdivisions of the Carboniferous system, the term Millstone Grit would never have been used either in Northumberland or Scotland. The beds in North Wales generally supposed to be the equivalents of the Millstone Grit, I think, on palæontological grounds alone, must be partly referred to the Carboniferous Limestone division. This series is the Cefn y Fedw sandstone. The upper part of the series, however, the Hollywell shale, seems to have a lower coal measure fauna which will be seen to be identical with that of the grits and the shales below them.

At Pule Hill, Lancashire, in a bed of ferruginous grit just below the horizon of the Pendle grit, is a marine band with numerous examples of Gasteropoda and Bellerophon, *Myalina Verneuilii*, *M. Flemingi*, *Schizodus antiquus*, *Sedgwickia attenuata*, and *Lingula*, which may in some way represent the Pendle limestones, and a most remarkable marine bed occurs about the same horizon at Congleton Edge, very rich in lower carboniferous forms, amongst which is *Productus cora*, *Orthis Michelini*, and *Athyris ambigua*. Several marine bands occur at intervals

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throughout the Millstone Grit Series and the Coal Measures, which contain mollusca with a Lower Carboniferous facies, but the individuals themselves are nearly always dwarfed. Mr Kirkby has shown that similar bands occur in the Fifeshire coalfield.

The Coal Measures as they approach the margin of the coal-fields in the Midlands are conformable with the grits. I think they were deposited in separate basins and never formed a continuous sheet, because in many coalfields the seams are separated by shales, etc., which diminish regularly in thickness as they approach the margin. They contain themselves beds of grit rock of varying thickness, so that it is difficult accurately even on lithological ground to limit each subdivision. The Coal Measures can be subdivided into three divisions with fair palæontological precision.

The upper series consist of beds of green and red marls with sandstones, and coals and ferruginous black band, and towards the base a series of limestones, probably of inorganic origin, but containing Spirorbis, a fossil which in the North Staffordshire Coalfield, however, is not limited to this series. But in England this division is characterised by the presence of *Anthracomya Phillipsii*.

The middle division is the chief coal-bearing division, and in it the genera *Carbonicola*, *Anthracomya*, and *Naiadites*, attain their highest development, both in numbers and species.

The lower or gannister division has a peculiar fauna which is common to it and the Bowland shales: some species of the family Carbonicola also occurring in these beds.

The Bowland shales and millstone grit beds are hardly represented at all in Belgium; the beds of Chokier, however, contain several species peculiar to the gannister fauna. Further east in Russia they seem to be conspicuously absent. Although the terms Yoredale and Millstone Grit have been applied to certain beds in Ireland, it seems to me that they are unsupported both by palæontological and lithological evidence.

So far I have produced only stratigraphical evidence from the field in support of my classification of the carboniferous rocks, but the evidence afforded by an examination of the palæontology of the various beds is even more emphatic than that derived from stratigraphical observations.

The Yoredale series of Wensleydale contain a fauna which, as far as I can ascertain at present, contains no species which are not common to it and the great Scar limestone below it, and to the "massif" of Derbyshire, unless the presence of *Edmondia sulcata* be an exception. The various beds of Lime-stone contain very similar faunas, some of the more important forms, though absent in the shales between them, reappearing

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again and again in the limestones. When we, however, get to Northumberland and Scotland, the fauna found in the shales differs in certain marked characters from that contained in the limestones, though, even here, my statement as to the faunas of the Yoredale limestones still holds good. The shales contain a larger Bivalve and Gasteropod fauna and fewer Brachiopoda and Actinozoa, a change probabably due to bathymetrical causes. The Posidoniella shales of Lancashire and Yorkshire contain a fauna totally distinct from that of the Yoredale limestones; the following species occur in them which I have never met with in the Carboniferous limestone series:—

Glyphioceras Davisi, Crick.
„ *bilingue*, Salter sp.
„ *reticulatum*, Phill. sp.
„ *diadema*, de Kon. sp.
„ *stenolobum*, Phill. sp.
Dimorphoceras discrepans, Brown sp.
„ *Gilbertsoni*, Phill. sp.
Posidoniella laevis, Brown sp.
„ *minor*, Brown sp.
„ *Kirkmani*, Brown sp.
„ *variabilis*, Brown sp.
Aviculopecten papyraceus, Sow. sp.

The latter shell has been stated to occur at lower horizons, but of the correctness of this statement I have grave doubts. The whole question of the distribution of this species is discussed towards the end of this paper.

The absence of the characteristic Carboniferous Limestone fossils is very noticeable, the ubiquitous Brachiopoda being barely represented. This fauna does not seem to have existed in Scotland or the extreme north of England, for although *Posidonia corrugata* is common in the shales this is a different genus from the Posidoniella of de Koninck.

Much has been done on the continent, both in Russia and Belgium, towards zoning the Carboniferous rocks, and the application of this work to British deposits, produces a very curious result, but I think on the whole the evidence obtained considerably strengthens my view.

The Carboniferous series of Russia has been divided into three stages, which may be briefly summarised as follows:—

Upper stage. With plant beds and coal in the Donetz.
- A. Horizon with *Spirifer fasciger*, *Conocardium Uralicum*, *Schwagerina princeps*.
- B. Horizon with *Productus cora*, *Marginefera Uralica*, *Spirifer supramosquensis*.
- C. Horizon with *Syringopora parallela*, *Ompalotrochas Whitnyi*, *Spirifer striatus*.

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Middle stage.	Horizon of *Spirifer Mosquensis.* Fusilina limestones.
Lower stage. With coal in Central Russia.	Horizon of *Productus giganteus, P. striatus, Chonetes papillionacea*, below which are deposits of clay with *Stigmaria ficoides*, and at the base a limestone with *Productus mesolobus.*

The chief authorities for the above statement are Tschernyschew (Ann. Soc. Geol. Nord France, tome xvii. 1890); Struvé (Mem. Acad. Imp. St. Petersburg, tome xxxiv. No. 6, 1886), and the various guides issued to members of the 7th International Congress by Nikitin (Central Russia), Tschernyschew and Loutonguin (the Donetz and the Urals).

With regard to this palæontological sequence I would add that, in the Donetz basin, the lists of fossils given as belonging to Horizon A, very few have been recognised in Western Europe, and the Fauna as a whole is very distinct from that contained in the beds below it, especially towards the top.

The exact zonal limitations of the Horizons A and B is not at all so satisfactory; for, according to the lists in the guide to Le Bassin du Donetz, six subdivisions occur in the middle stage, and *Productus cora* is said to occur frequently with *S. mosquensis* and *P. giganteus* (Struvé). On the other hand, both these forms occur together in the lower beds of the upper series, both above and below beds with *Spirifer supramosquensis*; but it also appears that *Sp. Mosquensis* is absent in beds containing *Spirifer fasciger*.

Spirifer fasciger is considered by Davidson to be a synonym of *Sp. duplicicosta* (Phillips). He says, "*Sp. fasciger* (Keyserling) evidently belongs to the same species and has been so admitted by Professor M'Coy." Mono. Brit. Carb. Brachiopoda, p. 25.

Mr Etheridge, in his paper on the "Palæontology of the coasts of the Arctic lands," Nares' expedition, Q. J. Geol. Soc., vol. xxxiv. p. 628, says, in his remarks on *Spirifer duplicicosta*: "Keyserling has described a species (*Spirifer fasciger*) from Petschora land . . . which certainly is the same as our British form and the *Spirifer duplicicosta* brought from Feilden Isthmus. This species is common and abundant in space and time through the carboniferous series; occurs everywhere in Britain and in many places in Ireland, Belgium, etc." It is sufficient for my purpose to add that this species occurs in the zone of *Productus giganteus* in Great Britain and Ireland, and in Belgium.

Productus mesolobus is also stated by Etheridge to occur at the same locality in Feilden Isthmus. It also is found in the

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uppermost beds of the carboniferous limestone, so that we are asked to believe that in Russia, species which occur together in Great Britain and in the Arctic lands are characteristic the one of the base and the other of the top of the Russian Carboniferous series.

Some question may be raised as to what still is meant by *Productus cora* (d'Orbigny), the original type coming from Bolivia. De Koninck saw the type and felt positive that it was identical with the European species, which had been described as *P. comoides* (de Koninck) and *P. corrugata* (M'Coy).

Dr Waagen has studied this question in his work on the Salt Range fossils. (Palæontologia Indica, ser. xiii., Salt Range fossils, p. 667-678). Shells from this region had been referred by Davidson and de Koninck to *P. cora*; but Waagen, while recognising the presence of that fossil there in the lower, middle and upper divisions of the series, says that there are certain allied forms which form a group the members of which differ between themselves and can be subdivided into

Group of—

Productus cora with no sinus, but occasional spines on ventral valve.

Group of—

P. Nefedievi with a general absence of spines and the presence of a median impression on the visceral part of the ventral valve.

Further he shows that *P. corrugatus* (M'Coy), possessing few or no spines and no sinus, differs from *P. cora;* and he describes a new species, *P. lineatus*, which has spines and a small ventral fold. Speaking of *P. corrugatus* (M'Coy), Dr Waagen says: "I have stated above that I consider this species as distinct on account of the general absence of spines on the surface, whereas these spines are never absent in *P. cora*. Otherwise *Prod. corrugatus* shows the same configuration and the same inflation of the ventral valve."

Trautschold described and figured a shell from the zone of *Sp. Mosquensis* at Miatchkovo as *P. cora*, which Waagen identifies with his *P. lineatus*, and he further states that "In the Upper Carboniferous beds, the Upper Carboniferous Limestone of Russia, the Coal Measures of America, etc., forms with surface spines occur exclusively." The figure given by Trautschold (Die Kalkbrüche von Mjaltschkowa, cap. v. p. 91), is certainly identical with M'Coy's *P. corrugata* and shows the presence of few spines, and this author considers the *P. Nefedievi* (de

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Verneuil) a synonym. It would therefore appear that *P. cora* occurs also in the middle division of the Carboniferous rocks of Russia.

The form of *P. cora* which occurs in Great Britain is that described and figured by Davidson as *P. corrugata*, by M'Coy, *i.c.*, with few spines and no sinus; but Davidson is careful to state of *P. cora*: "Ventral valve gibbous, evenly convex, or slightly flattened along the middle"; and again, "Spines few in number, sparing, scattered over the surface."

Are the small differences adduced by Dr Waagen sufficient for the erection of so many species? It appears that it is a question of the number of spines and a small sulcus in the ventral valve, and that on these facts, themselves not constant, four different species are retained:—

P. cora with spines, and
P. corrugatus with few spines;
P. Nefedievi with few spines and a ventral sulcus;
P. lineatus with spines and a ventral fold.

It is a well-known fact that in all shells the absence or presence of the non-vital characters, such as external ornament, spines, and even the number of hinge teeth, depend on the environment, a highly-ridged and ornate species becoming almost plain under altered conditions. It is also well established that numerous species of *Productus* often lose or acquire a ventral sulcus, even in the same locality. For example, I have a large series of *P. humerosus* from the limestone of Cauldon Low, Staffordshire, which show all the transitions from a perfectly convex ventral valve through a sulcated form to one with an acute ridge with spines in the centre of the sulcation, and I have also obtained from a single horizon *P. cora* without spines, with spines, and with and without a median sulcus in the ventral valve, but I am prepared to admit that in some places the spined varieties do occur more frequently than those forms without such appendages.

If, then, *Productus cora* and *Spirifer fasciger* are identical with those shells which are generally recognised in the West of Europe as *P. cora* and *Sp. duplicicosta*, both of these species occur with *P. giganteus* in Great Britain and they must be regarded as of little value for the purposes of the identification of horizons by zonal forms, at great distances; but there is, perhaps, more evidence from lower forms of life that the Upper Carboniferous beds of Russia have a somewhat distinct fauna from that which is found in the upper part of the Carboniferous Limestone series in Belgium and Great Britain.

It is to be noted also that *Spirifer striatus* is stated to be

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characteristic of the lower bed of the upper stage, but neither in Struvé's work or the lists given in the Donetz guide can I find that this species occurs in the lower division.

It seems to be fairly conclusively settled that *Spirifer mosquensis* and *Productus cora* are not met with in the lower stage.

It is interesting to note that two genera of Brachiopoda, *Enteletes* and *Meekella*, occur in the middle and upper divisions, and are not known in the carboniferous beds of Western Europe, though these are present in beds of carboniferous age in the Salt Range, India, and in North America.

In Belgium de Koninck and Dupont have attempted to establish three stages in the carboniferous deposits, but their work has not been universally received by Belgian geologists.

These stages are—

Superior. VISEAN, with *Productus giganteus; P. striatus, P. punctatus, Chonetes papillionacea, Spirifer glaber, Sp. bisulcatus, Glyphioceras sphæricum*, and *G. striatus*, and with a bed of *Productus cora* towards the base.

Middle. WAULSORTIAN, with *Amplexus coralloides, Syringothyris cuspidatus, Spirifer striatus.*

Inferior. TOURNAISIAN, with *Spirifer Tornacensis, Sp. cinctus, Sp. laminosus, Syringothyris distans, Athyris Royssii, A. lamellosus, Orthis Michelini.*

Till recently (1883) it has been supposed that *Spirifer Mosquensis* occurred in Belgium in the Tournai beds, and that the Viséan series were at the base, because they rested immediately upon beds of Devonian age. De Koninek at that date published a paper on *S. mosquensis* (Bull. de Mus. Roy., 1883, tom. ii. p. 371), in which he showed that he had been mistaken in the identity of the fossil, and showing that the Belgian specimens differed from the Russian species, and proposing the names of *Spirifer cinctus* and *Sp Tornacensis* for the former. A fair number of drawings are given of each species and of others of somewhat similar shape, and the following is a translation of what is said under the head of "Rapports et différences" at the end of the description of *Sp. cinctus*. "In 1842 I confounded this species with *Sp. mosquensis*, which, by the variations which the relation of the various dimensions undergo according to age, and from the structure of its radiating ribs, has some analogy with it. I have already remarked that it differs essentially by its great size, and further still by the absence in the ventral valve of diverg-

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ing dental lamellæ so strongly developed in its Russian congener."

Sp. Mosquensis has the following proportions: transverse diameter, 45 mm.; vertical diameter, 55 mm.; *Sp. cinctus*, 85 : 92.

I am inclined to accept de Koninek's view, and would say that *Sp. cinctus* and *Sp. Tornacensis* occur in the carboniferous limestone of Limerick. There will be little difficulty in distinguishing between *Sp. Mosquensis* and *Sp. Tornacensis*; the latter being always tranverse, its area somewhat shorter than the greatest transverse diameter, and the radiating striæ fewer and deeper, and is more allied to *Sp. striatus*, from which I should not like to say it is distinct. *Sp. cinctus* has its transverse diameter somewhat longer than that from the beak of the ventral valve to the opposite edge, the area being a little shorter than the transverse diameter, the sulcus and fold being very slightly developing, its margin extending beyond the rest of the edge of the valve, the connecting border being concave on both sides, and the radiating striæ, though numerous, are much larger and broader. In *Sp. Mosquensis* the transverse is shorter or equal to the other diameter, the sulcus is well marked in the ventral valve, its free border is not emarginated but elevated, and the striæ are very numerous and flat.

The young forms of *Sp. cinctus* are relatively more transverse than the adult. Professor de Walque thinks that de Koninck was in error in referring this species to Keyserling's *Sp. cinctus*, and proposes the name *Sp. Koninekı*, unless it is established that they are only variations of their ancestor, *Sp. Tornacensis* (Ann. Soc. Géol. Belge., tome xxii. p. xlvi.).

In de Koninck's latter work (Ann. Mus. Roy. d'hist. Mat. Belg., 1885) he describes two more species, *Sp. suavis* and *Sp. spissus*, from the Waulsortian and Viséan stages respectively, which seem to resemble *Sp. Mosquensis* more closely in shape, though they do not appear to possess so many ribs; but as I have not seen these specimens I am unable to pronounce with certainty upon their affinities as I have not been able to examine them. The species invented by de Koninck must be received with a certain amount of hesitation, because he avowed that he thought he was justified in considering any form which varied constantly, in however slight a degree, a different species, provided that it occurred at a different horizon.

Perhaps the bent of de Koninck's mind towards the erection of species may be best obtained from the following analysis of his great work on the Fauna of the Carboniferous Limestone of Belgium, which was not completed when he died in 1887.

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Altogether 1123 species are figured and described,

Lamellibranchiata . . .	461
Gasteropoda	499
Brachiopoda, not completed . .	130
Goniatites	33

which are distributed as follows:—

	Viséan	Waulsortian	Tournasian	Total
Lamellibranchiata, .	222	158	81	461
Gasteropoda, . .	283	95[1]	122	500
Brachiopoda,[2] . .	64	37	29	130
	Upper. Lower.	Upper. Lower.		
Goniatites, . . .	18 + 1	3 3	10	35
	588	296	242	1126

So that only one Gasteropod and two Goniatites occur at more than one horizon, the former is marked with a ? as a doubtful diagnosis, and the two Cephalopoda are common to both stages of the Waulsortian.

This is a condition of things utterly different from that which obtains either in Russia or Great Britain, and one that an examination of the Belgian specimens will not endorse. Professor de Walque has pointed out in several papers that many of de Koninck's species occur as other horizons. In the "Légende" of the geological map of Belgium, published in 1896, the following stages of the Carboniferous rocks are indicated.

Houiller
- Étage moyen ou houiller proprement dit.
- Étage inférieur
  - Poudingue.
  - grès, Psammites, schistes, calcaire encrinitique, houille maigre.
  - Phtanites and schistes, siliceux, ampélites, sans houille.

Étage Viséan
- Assise de Visé
  - Calcaire à *Productus giganteus* and *P. striatus* with beds of anthracite.
  - Calcaire noir et gris.
  - Calcaire à grains cristallin, oolithique ou compacte *Productus cora.*

[1] One specimen doubtfully given as occurring in the Waulsortian stage as well as the Viséan.

[2] Only Dielasma, Rhynchonella, Camarophoria, Athyris, Retzia, Acambona, Spirifer.

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Étage Viséan	Assise de Dinant.	Calcaire noir et bleu à crinoides, grande dolomie *Chonetes papillionacea*. Marbre noir de Dinant en partie avec cherts noirs souvent dolomitisé.
Étage Tournaisian	Assise des Écaussines et de Waulsort	Calcaire à crinoides, à *Spirifer Koninckı* (cinctus). Calcaire d'Yvoir, à *Sp. Koninckı*.
	Facies Walsortien, lithological characters only.	
	Assises d'Hastière	Calc schist and calcaire noirs argilleux, calcaire à crinoides. *Spirifer Tornacensis*. Schistes foncés, *Spiriferina octoplicata* and *Spirifer Tornacensis*. Calcaire noir et bleu a crinoids avec schistes intercalés à *Phillipsia*, gros *Spirifer glaber* et *Sp. Tornacensis* abondants.

In this classification it must be noted that the WAULSORTIAN of Dupont and de Koninck is only considered as a local phase of the TOURNAISIAN.

One very important palæontological fact, however, seems fairly conclusively established, and that is the presence of *Productus cora* in beds below that with *P. giganteus*. In Russia the reverse is the case, *P. cora* being characteristic of the superior division, while *P. giganteus* is never found above the lower division. Speaking broadly, too, the whole of the fossils mentioned above as distinguishing the threefold division of de Koninck and Dupont are found at the same horizon in Great Britain and Ireland, and I have obtained myself five out of the seven species given as typical of the Tournaisian, in beds which contain *Productus giganteus*, in Derbyshire, which are the very topmost beds of the Carboniferous Limestone. Several short notices by de Koninck and Professor M. Lohest have been published on the parallelism between the limestones of Ireland, the Bristol and the Pennine districts, and the various stages as shown in Belgium; but unfortunately de Koninck founded much of his views on the examination of museum specimens, and Professor Lohest has relied chiefly on lithological similarities, and observations limited to very small areas. I have lately reviewed in detail their conclusions and may sum up my

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deductions, that however possible it may be to state precisely the zones in which certain fossils occur in Belgium, the same species have not such a distinct horizontal limitation in the Carboniferous beds of Great Britain and Ireland. For according to the zones as determined for Russian Carboniferous beds, the upper two Russian zones are absent in Belgium, which, on the other hand, possesses a distinct zone (*coal measures*) above, and the *Tournaisian* below, which are not apparently represented in Russia, and though the two deposits may be contemporaneous in time, we can hardly on palæontological grounds recognise the coal measures of Belgium as the equivalents of the zone of *Spirifer Mosquensis* and *Productus cora* and *Spirifer fasciger* in Russia. It appears too that the Belgian succession is never found in situ, and therefore it may have been, as de Koninck thought at first, that the Viséan and Tournaisian faunas were contemporaneous, but lived in separate marine basins. For the present, it is impossible to compare the faunas of the Carboniferous beds of North America with those of Europe, owing to the fact that, whether correctly or not is impossible at present to be stated, American palæontologists have given new names to nearly every species occurring in them. Broadly speaking, I believe that the following generalisation is correct: the fauna of the Carboniferous beds east of the Rocky Mountains have a great faunal resemblance to those of Western Europe, while those beds west of the Rocky chain have in their faunas a greater affinity to Indian and Russian Carboniferous beds. In the synopsis of the American Fossil Brachiopoda Bul., U.S. Geol. Surv., No. 87, 1897, *Productus cora* and *P. giganteus* are quoted from Upper Carboniferous, *P. cora* being stated to occur "throughout the Upper Carboniferous of North America; Itartuba and Barreirinha, Brazil; Yampopata, Cochabamba and Lake Titicaca, Bolivia." *P. giganteus* is only quoted from Shasta County, California.

In this work the Carboniferous series of N. America is classified as follows:—

Eo Carboniferous.	Meso Carboniferous.	Neo Carboniferous.
Kaskaskia, St Louis.		
Keokuk, Burlington.	Coal Measures.	Permian.
Kinderhook.		

In the table *P. cora* seems to be limited to the coal measure group, and *P. giganteus* to the Kaskaskia and St Louis group. The other species used as zonal forms in Europe have not yet been recognised in North America.

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	BRISTOL.	DERBYSHIRE.	WENSLEYDALE.	NORTHUMBERLAND.	SCOTLAND.	IRELAND.
UPPER.	Upper and middle coal measures.	Upper, middle, and lower coal measures.	Coal measures absent.	Middle and lower coal measures.	Upper and middle coal measures.	Middle and lower coal measures.
	Millstone grit and Bowland shales.	Millstone grit and Bowland shales, with the Pendle side limestone.	Millstone grit very thin. Bowland shales absent or only represented by about 100 feet.	Millstone grit and Bowland shales die out.	Millstone grit and Bowland shales absent.	Millstone grits and Bowland shales probably absent.
LOWER. Carboniferous Limestone series.	With *Productus giganteus* from base to top.	With *Productus giganteus* through whole extent, especially at the top.	With *Productus giganteus* in the great Scar and all the Yoredale limestones to the main.	Carbonaceous series with *Productus giganteus* throughout.	With *Productus giganteus* in the Upper and Lower Divisions.	With *Productus giganteus* throughout the whole.
Lower Limestone shales.	600 feet with *modiola Macadamii*	Base unknown.	A few feet of conglomerate with corals.	Calciferous series with *Modiola Macadamii.*	Calciferous sandstone series with plant beds and limestone *Productus cora* in the upper part in Fife and *Schizodus Pentlandicus modiola Macadamii.*	The Coomhola and Moyola grits with *Modiola Macadamii.*

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The preceding scheme shows my conclusions as to the various equivalents of British Carboniferous rocks divided into two divisions based on broad palæontological lines.

It will be seen at once that in Great Britain and Ireland the zone of *Productus giganteus* is very largely developed, and characterises the whole of the calcareous deposits occurring equally throughout the Yoredale series of Phillips and the great Scar limestone below it: but above and below these lines it has never yet been recorded. This may very fairly account for the fact that we find in British deposits, that those fossils, which in Belgium only survived for certain definite periods, were able to exist throughout the whole period, and we therefore get a complete mixture of the Tournaisian and Viséan faunas; but, on the other hand, we are not able even to assert that any of the Lower Carboniferous fauna of Belgium came into existence in the British area before those of the Viséan, but both seem to have arrived there simultaneously.

De Koninck thought that he recognised that the limestones of Hook Point, Dublin (subsequently omitted), Limerick and Armagh had a Tournaisian fauna, and so far he was correct, but he did not notice that *Productus giganteus* and other typical Viséan fossils were also present.

The question of the occurrence or not of *Spirifer Mosquensis* in Great Britain is an important one, but one which I have not yet been able to decide. The evidence is as follows:—Davidson figured in his monograph on the British Carboniferous Brachiopoda (pl. iv. figs. 13, 14) two examples, one said to be from Derbyshire, belonging to Cambridge University, and one from Little Island, Ireland, in possession of the Royal Dublin Society; unfortunately the former specimen has disappeared and I have not been able to see the other, but I must confess that the figures cannot be differentiated from examples from Russia. In the appendix published in 1880 it seems that Davidson thought *Sp. Mosquensis* might be only a variety of *Sp. striata*, but he gives figures of two specimens which have a shape similar to that of *Sp. Mosquensis* under the name *Sp. trigonalis var. bisulcata*, from the upper limestones of the West of Scotland (pl. xxxiv. figs. 3 and 4). Davidson says himself of one of these specimens: "It is very deep between the valves and comes very near to *Spirifer Mosquensis*, a species not hitherto recognised in Scotland, being only distinguished from it by its fewer ribs." In the appendix and summary published a few years later, however, Davidson accepted without comment de Koninck's view that the species did not occur in either Belgium or Great Britain.

Dr John Young has kindly compared these Scotch specimens with one of *Sp. Mosquensis* from the middle carboniferous of

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Miatchkovo, near Moscow. He says that while allied to that species in form the Scotch examples have fewer ribs, only 40 compared with 70, and the fold on the ventral and dorsal valves are deeper. I have also examined a series, sent me by Mr J. Neilson, as possible specimens of *Sp. Mosquensis*, from the Upper Limestone Series of the neighbourhood of Glasgow, but they are quite distinct, having fewer ribs and those covered by regular and conspicuous herring-bone imbrications. The dorsal and ventral folds are more elevated, and the contour transverse rather than deep.

Dr Young tells me that he has a specimen from Co. Cork which, though larger, agrees very closely with *Sp. Mosquensis* in shape and the number of ribs, so that it is possible that the species occurs in Great Britain, but it seems to be a very rare form with us.

I have been able, by the kindness of the Director-General of the Survey, to examine the series of Spirifers named *Sp. Mosquensis* in their collection at Dublin. I do not, however, recognise one specimen of this species amongst them, but the series contains fine examples of *Sp. cinctus* (Koninck) and *Sp. Tornacensis* (de Koninck). Both these species, I may repeat, are stated to be confined to the Tournaisian of Belgium.

Through the kindness of Professor Lloyd Morgan I have been able to satisfy myself that the shell named *Sp. Mosquensis* by Stoddart from the lower limestone of Clifton is not that species but probably *Sp. planata* (Phillips).

The beach beds at the top of the mountain limestone of Derbyshire contain thousands of examples of *Productus giganteus* and its varieties, but above this horizon it is never found in that country. Although at a few horizons bands containing a fauna with the faces of the zone of *P. giganteus* occur in the millstone grits and coal measures, yet the zonal form itself never recurs and the beds are limited in extent to a few feet. The lower coal measures, grits, and Bowland or Posidoniella shales are characterised by the peculiar fauna mentioned above, none of the species of which are known to occur in the Lower Carboniferous Division. This fauna is a marine one, but is never present with the recurrent faunas from below, and fresh water beds with the coal measure genus Carbonicola are known low down in the series at Pule Hill, near Marsden, though they too are never actually associated in the same beds with the typical fauna of the series.

The horizontal distribution of *Productus cora* in Great Britain and Ireland is interesting when compared with the occurrence of that fossil in Russia and Belgium.

The highest horizon at which I have yet obtained it is from

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a concretionary calcareous band in the Posidoniella shales of Congleton Edge some few hundred feet below the third bed of millstone grit. This bed is several hundred yards above the mountain limestone which outcrops at the foot of the hill, above which I have never been able to find *P. giganteus*. On the other hand, *P. cora* occurs at various horizons throughout the zone of *P. giganteus*, being more common in the upper than in the lower beds. Mr J. Kirkby records the presence of this species in the upper 500 feet of the Calciferous Sandstone Series of Fifeshire. Thus the zone of *P. cora* in Great Britain overlaps both above and below the zone of *P. giganteus*, while in Russia this species is only found above that zone, and in Belgium, below it. *Spirifer glaber* is considered to be a typical zonal form of one of the lower beds of the Hastière facies of the Tournaisian. In Great Britain I have obtained very large examples of this, one of the commonest, species in the upper beds of the zones of *Productus giganteus* at Castleton, Derbyshire, Cracoe, Yorkshire, and from my own experience in collecting fossils I should say that it was much less frequently met with in the lower than in the upper beds of this zone. Stoddart, however, records its presence in the Oracanthus bed near the top of the lower limestone shales of the Avon section.

Chonetes papillionacea has in Great Britain a distribution which is practically identical with the zone of *P. giganteus*, and we are unable to identify a lower or any horizon to which the fossil is peculiar, as in Belgium.

Orthis Michelini is another fossil which with us has a very wide horizontal distribution, occurring in beds (Congleton Edge) far above the top of the zone of *Productus giganteus*. In Belgium it is stated to be limited to the lower beds.

The peculiarities of the distribution of the species alluded to above, in the Carboniferous rocks of Great Britain, will at once account for the difficulties in correlating them with their European equivalents, but I venture to hope that a better appreciation of the various equivalents in Great Britain itself may render this task somewhat less difficult.

A word or two is necessary with regard to certain of the species which I have suggested as zonal forms in my scheme, p. 360.

Modiola Macadamii.—I have shown in my monograph on the Brit. Carb. Lamellibranchiata that Portlock described under this term two distinct species, and one other as a variety. I therefore use this term as restricted by me. This species has however been quoted by Binney, Dugdale, Hull, and others as occurring in the upper and lower coal measures of the Lancashire coalfield. This, I am sure, is due to an

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erroneous identification. Mr H. Bolton (Proc. Mand. Lit. Phil. Soc., vol. xli., pt. iii.) has shown that the shell quoted by Dugdale (Trans. Mand. Geol. Soc., vol. xix.) belongs to the genus Anthracomya, and I think that Binney's shell will turn out to be *Anthracomya Phillipsii*, for Hull quotes him at p. 10 of the Geol. Surv. Memoir, "The Country round Prescot," as the authority for the occurrence of *M. Macadamii* in the upper coal measure marls of Sutton. I have never yet seen any other bivalve shell at this horizon than *A. Phillipsii*.

Aviculopecten papyraceus.—In England and Ireland this species is certainly typical of a certain horizon from the base of the Bowland shales to the gannister series. Authors have quoted its occurrence at other widely different horizons. Baily states ("Characteristic British Fossils," pt. i. Palæozoic, p. 113): "This very characteristic coal measure fossil has also been found as low down in the series as the carboniferous slate, where it was obtained at Clonakilty, Co. Cork . . . and identified by the author." I have had the privilege of examining these specimens, now in the collection of the Geological Survey of Ireland, and am able to state with certainty that the species are quite distinct. The Clonakilty specimens are of different shape, and have the ribs covered by a series of tubercular nodules, which is not the case with *A. papyraceus*.

Baily goes on to say: "Professor J. Phillips also mentions its occurrence under the name *Pecten papyraceus* in Carboniferous Limestone near Harrogate and in Bolland," but this is incorrect. Phillips says: "*P. papyraceus* is found near Harrogate and in Bolland," and omits the words Carboniferous Limestone, which are an invention of Mr Baily. Indeed, the Carboniferous Limestone does not crop out anywhere near Harrogate but which is situated near Millstone Grit country, in which beds the shell ought to occur. With regard to Bolland, this is a district in which the Bowland shales occur as well as the Carboniferous Limestone. This explanation is important, because Mr R. Etheridge also follows Baily, and erroneously makes Phillips say Mountain Limestone, and goes on to say, "My father informs me that specimens from the Mountain Limestone are in the Oxford Museum." I have made inquiries, but cannot ascertain that this is so. There is a species of *Aviculopecten* in the Mountain Limestone of Derbyshire, probably as yet undescribed, which has a certain resemblance to *A. papyraceus*, and which may be mistaken for it by those who do not know the species, but they are quite distinct. Baily also states that *A. papyraceus* occurs in the Upper Carboniferous Limestone of Co. Dublin, a statement the correctness of which I doubt.

In Scotland, however, *Aviculopecten papyraceus* undoubtedly

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does occur at an apparently different horizon from that in which it is found in England, namely, East Kilbride, in shale 2½ feet above the Calderwood cement stone, Glebe quarry, a locality generally considered as that of the Lower Carboniferous Limestone group. Talking the matter over with Mr J. Neilson, he informs me that possibly this is a mistake, and that the beds here should be relegated rather to the Upper Carboniferous Limestone series, advancing both palæontological and lithological reasons in support of this view. Mr R. Etheridge figured specimens from this horizon (*Geol. Mag.*, Dec., II., vol. iii. p. 152), and I have been able to examine specimens from this locality in the Patton collection, Museum of Science and Art, Edinburgh, and in the private collection of Mr J. Neilson.

As a result of the distribution of the Carboniferous fossils discussed above, it would seem that in Great Britain we have, in our Lower Carboniferous Series, one zone only, that of *P. giganteus*, in common with Belgium and Russia, which is the upper zone of Belgium and the lower zone of Russia. That the period during which this zonal form existed in Great Britain must have been very great, is shown by the great extent of its vertical distribution, and also from the fact that the faunas with which it is associated appear to have been much more extensive than obtained at any one time on the Continent.

A comparison of the faunas contained in the shales and limestones of the zone of *Productus giganteus* shows that they differ, as might naturally have been expected, somewhat considerably, and, in consequence, the fauna which occurs in this zone in Derbyshire and South-West Yorkshire contains many species which do not appear at all in Scotland; and, on the other hand, the Scotch beds have many species peculiar to themselves. This is due to the different conditions under which the detrital and organic sedimentary deposits were laid down. It is an undoubted fact that as the beds pass north, the limestones are split up, dwindle in thickness, and are separated by beds of sandstone and shale, which rapidly increase in importance to the north. This fact undoubtedly points to shallower water and a closer proximity to land in this direction, and consequently to sublittoral and shallow water conditions, and therefore the shales contain a fauna rich in Lamellibranchs, Crustaceans, and other animals of a similar bathymetric habitat, while the limestones are characterised by Brachiopoda and Actinozoa, which need a clear, salt water environment, free from muds and detrital sediment.

During the time that a continuous organic sediment was being deposited in the Midlands of England and the greater part of Ireland, shore and estuarine deposits, with occasional beds of coal, denoting land conditions, were being laid down in

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Scotland and Northumberland. At times, however, the sea seems to have made inroads northward and the environment to have become suitable for the partial migration northwards of the fauna which was living in profusion in the south and west, for the time represented by any bed of limestone; but these conditions did not last long enough for any but the most hardy species to establish themselves, for the Scotch limestones contain a fauna nothing like so rich as that of the Midlands in Lamellibranchs and Gasteropoda or Cephalopoda.

It is quite probable that many of the beds of limestone die out as they pass north, and should it be that the lower beds disappear the zone of *Productus giganteus* becomes narrower vertically.

It is, however, quite apparent that in such a case the beds which are actually the equivalents in time of those of this zone, do not contain the characteristic fauna, or even appear to belong to another zone, because conditions were such that the several species could not survive in an altered environment; and it is a necessity that such a state of things must occur at a point where littoral, sublittoral or marine conditions pass into each other. Life zones will be made out more easily in a series of deposits of continued sequence, such as obtains in the Jurassic and Cretaceous rocks, but when the series of beds is a sequence of repetitions, zonal forms will be fewer and of wider vertical distribution: the hardy and primitive forms will tend to survive rather than those which exhibit a disposition to vary.

In the case of the Carboniferous rocks in Great Britain, therefore, it seems to me to be impossible to use the zonal fossils as indices of contemporaneity with any degree of exactness, but they are rather indicative of the conditions and depth of the deposit. We have no series of evolving forms in the Carboniferous rocks like the Ammonitidæ or the Graptolites, but a remarkably hardy set of animals, some of which could stand salt, brackish, clear and muddy waters, and reappeared at many horizons in all the marine or fresh water beds from the base to the top of the Carboniferous rocks. There is no doubt that terrestrial, littoral and marine conditions existed contemporaneously in Great Britain throughout the whole of the Carboniferous epoch, and that there was a constant migration of species backwards and forwards as these conditions slowly changed, so that in some places contemporaneous faunas became successive, as may be expressed in the following diagram at A B, which represents a series of overlaps of estuarine and marine beds, which are being continuously deposited in their own areas. Let us suppose that one fauna is found in the series of beds E F and another in the series C D. In the series A B contemporaneous

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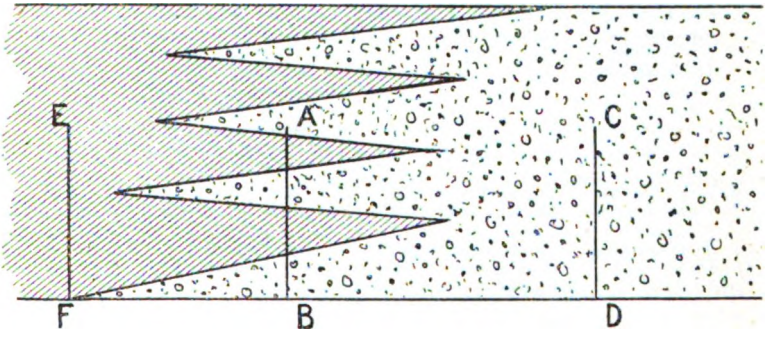
faunas therefore become successive. I regard the Calp series of Ireland, very local in its occurrence, as due to the prevalence of estuarine conditions in certain localities between the marine deposits of the Upper and Lower Limestones, which was therefore of very temporary character, in distinction to the general prevalence of such conditions in Northumberland and Scotland.

In Belgium the whole of the Lower Carboniferous rocks seem to have been deposited under somewhat similar conditions, which were essentially marine, and they were evidently laid down at such a distance from land that detrital sediment and estuarine conditions were entirely absent. In Russia and North America, on the contrary, estuarine and marine conditions alternated through a greater part of the Carboniferous epoch; in Russia especially during the deposition of the Upper and Lower divisions.

Theoretically, then, life zones should be more conspicuous in Belgium and in the thick strata of limestone in Derbyshire, but



up to the present, although certain broad zonal horizons have been fairly well established in Belgium, the English beds have yielded no results in this direction. The twofold division of the carboniferous rocks of Great Britain is well established palæontologically. There is a great break in the fauna at the top of the Carboniferous Limestone of Derbyshire and its equivalent, the top of the Yoredale series in Wensleydale and the Carboniferous Limestone series in Scotland. Above this horizon, it is true that in a few thin bands dwarfed representatives of species found in the lower beds do occasionally reappear, but as a whole this line marks a very distinct change in the Molluscan and Actinozoan fauna. Dr Traquair has shown that at this horizon a similar marked change occurs in the fish fauna both generically and specifically, and Mr Kidston arrives at practically the same opinion on the evidence of the flora of the Carboniferous period. He has, however, in company with many

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others to the present, not understood the real equivalents and the essential difference in the vertical position of the Bowland shales and the Yoredale series of Wensleydale.

The following table shows to what extent at present I have been able to go in dividing up the Carboniferous rocks of Great Britain and Ireland into zones; and it will be at once noted that many of these zones are of very great vertical thickness :—

	ENGLAND.	SCOTLAND.	IRELAND.
1. Zone of *Anthracomya Phillipsii.*	Upper Coal-measures of Lancashire, Yorkshire, Staffordshire, Bristol, including the *Spirorbis* Limestones.	The Red Beds of Fifeshire.	? Wanting.
2. Zone of *Naiadites modiolaris* and *Anthracomya modiolaris.*	Middle Coal-measures universally.	The Coal-measures of Fifeshire.	Coal-measures.
3. Zone of *Aviculopecten papyraceus, Gastrioceras carbonarium, Posidoniella laevis,* and *P. minor.*	Ganister Series. Millstone Grit. Shales below the Millstone Grit universally.	? Wanting. NOTE. — *Aviculopecten papyraceus* is said to be found some distance above the Ell Coal in the Wishaw district, Lanarkshire; but I have never seen this fossil in any Scotch collection, and the determination is possibly erroneous.	Castlecomer, Leinster, Coalfield. Coal-measures of Fynes, co. Limerick.
4. Zone of *Productus giganteus* and *Productus cora.*	The Carboniferous Limestones of Derbyshire. The measures from the Great Scar to the Main Limestone, N. Yorkshire. The Carbonaceous Division of Northumberland. Carboniferous Limestone of Wales and the Mendips.	The Carboniferous Limestone Series of Scotland { Upper, Middle, Lower.	The Upper Limestone The Calp The Lower Limestone.
5. Zone of *Modiola Macadamii.*	The Lower Limestone Shales of the Mendips and South Wales, with several fossils common to the Old Red Sandstone Series and the Carboniferous.	The Calciferous Sandstone Series, with *Schizodus Pentlandicus* and *Sanguinolites Abdensis* in Fifeshire, and a fauna very different from the English and Irish equivalents. Mr Kirkby states that *Productus cora* is contained in the upper 500 feet of these beds.	The Coomhola and Moyola beds, forming a passage from the Old Red to the Carboniferous, and containing certain fossils common to both.

Series 1-3 constitute what I consider to be the "Upper Carboniferous," and series 4 and 5 the "Lower Carboniferous," of my paper on the Yoredale Series (*Geol. Mag.*, April and May, 1897).

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XLIX.—*Notes on the Correlation of the Lower Carboniferous Rocks of England and Scotland.* By WILLIAM GUNN, F.G.S., of H.M. Geological Survey of Scotland. (Plate XXa.)

(Read 20th January 1898.)

THE object of the following paper is to show that the group of Lower Scottish Limestones about Dunbar and round the Midlothian Coalfield does not represent any part of the Mountain Limestone of Yorkshire, but is the equivalent of the upper part of the Yoredale Series of Phillips, while the Edge Coals and Upper Limestones of Midlothian represent a series of beds which in Yorkshire and Northumberland lie above the true Yoredale Series of Phillips, and which were included by him in the Millstone Grit. It necessarily follows from this correlation that the lower part of Phillips' Yoredale Series, together with the Scar or Mountain Limestone of Yorkshire, are represented in Scotland by the Calciferous Sandstone Series, which is mainly a fresh-water deposit.

This correlation of the Lower Carboniferous rocks of the North of England with those of Scotland was made in the year 1881, after an examination of parts of the coast of Haddingtonshire and Berwickshire in company with two of my colleagues, Mr H. H. Howell, now Director of the Geological Survey, and the late Mr W. Topley, who both accepted at the time the general views here stated. Mr Topley thought them of so much importance that he wished to join with me in writing an elaborate paper on this correlation, and I drew up some notes on the subject, but for various reasons the paper was never completed or published. However, the principal results have been from time to time orally communicated to several of my colleagues.

To illustrate the paper vertical sections are given which represent the rocks below the Millstone Grit in four localities, each section being drawn to the scale of 600 feet to an inch. The most southerly of these gives the succession of beds from the top of Ingleborough down to the basement conglomerate which rests unconformably on the highly inclined Silurian rocks. The lower part of the section is composed of a mass of limestone, 600 to 700 feet in thickness, while the upper part consists of an alternating series of sandstones, shales, and limestones, to which Phillips gave the name of Yoredale Rocks, because he considered they were typically developed in Yoredale (Wensleydale). In this and the other sections the limestones are particu-

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larly marked, because it is principally by means of them that the rocks in different places are correlated. The Yoredale Series, then, in the Ingleborough section ranges from the Hardraw Limestone up to the highest limestone—the Main or Twelve-Fathom—but two of the limestones generally occurring elsewhere are wanting in this section, so that it is certainly not a typical one of the Yoredales. Above the Main Limestone here there occurs a thickness of 100 to 120 feet of shale, and the hill is capped by coarse Millstone Grit.

The Wensleydale section is mainly that proved in Keld Heads Mine between Leyburn and Redmire. It will be noticed at once that the Yoredale Limestones are here both thicker and more numerous than at Ingleborough. Four of the limestones are each about 60 feet in thickness, whereas only the Main Limestone on Ingleborough attains this thickness. The two additional limestones are the Underset, and the thin Limestone next below. It should be stated that the Underset is here abnormally thin, it being usually about twice the thickness given. The 'Fossil' Lime, on the other hand, is usually only about one-half of the thickness here given, so it must be understood that the section does not stand for the whole of Wensleydale. The Main Limestone is often, perhaps generally, considerably more than 60 feet thick; in fact, it obtained the name of 'Twelve-Fathom' because it approximates to 72 feet in thickness. The upper part only of the Mountain Limestone is to be seen in Wensleydale, and its total thickness here is unknown, but it has already, as far as its upper members are concerned, begun to admit intercalations of sandstone and shale, and thus to approximate in character to the Yoredale Series above. In the dales to the north of Wensleydale somewhat similar sections may be obtained, and therefore it is unnecessary to give a detailed account of each. In the first valley, that of Swaledale, the section is very like that of Wensleydale, except that some of the limestones are thinner. In Teesdale we find that the Middle Limestone has separated into three limestones known as Scar, Cockleshell, and Singlepost Limestones, while nearly all the Yoredale Limestones, except the Main, are considerably thinner than in the dales farther south. Several comparatively thin limestones represent the upper part of the Great Scar Limestone of Ingleborough, while the lower part is a solid mass of limestone about 200 feet in thickness, known locally as the Melmerby Scar Limestone. Below this is a variable, but not thick, basement conglomerate, resting on the Silurian rocks which are exposed in the valley between the High Force and Caldron Snout. Not many miles to the west, in the Pennine escarpment, a thick series of sandstones occurs below the

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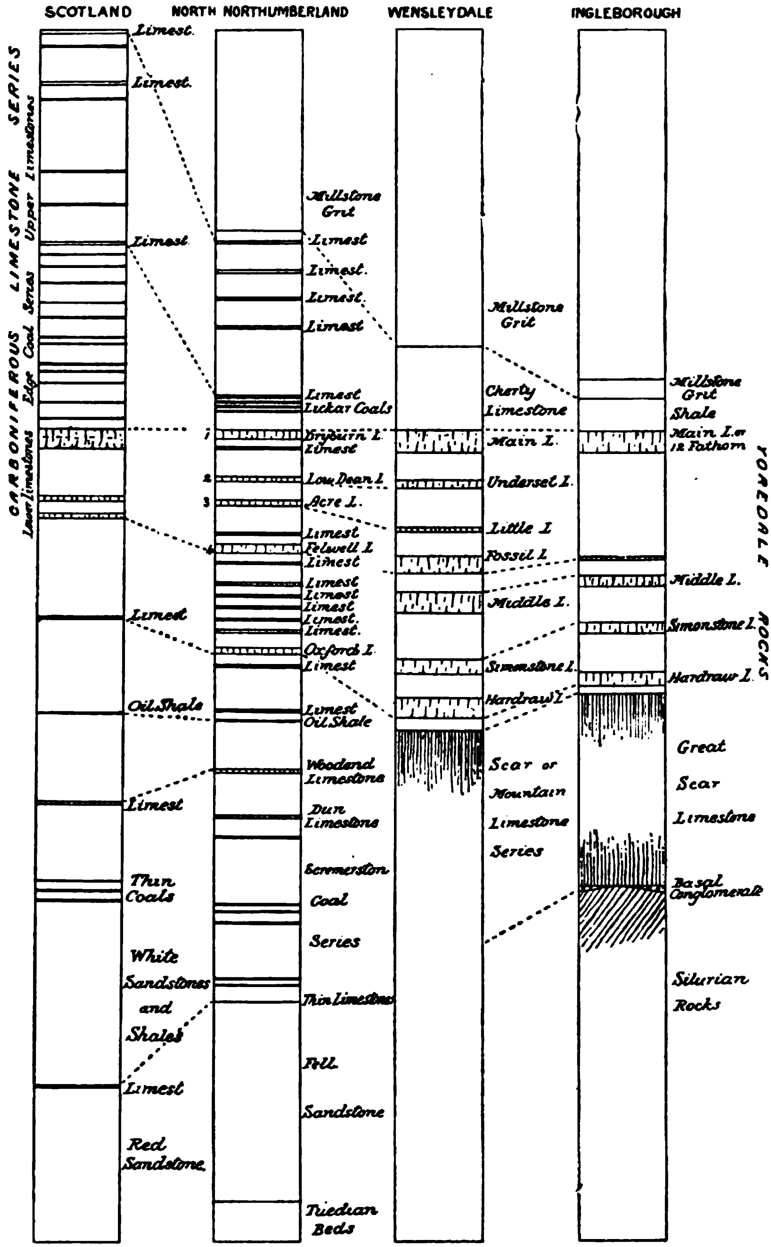
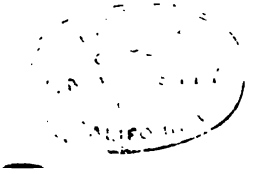

SCOTLAND
NORTH NORTHUMBERLAND
WENSLEYDALE
INGLEBOROUGH
CARBONIFEROUS LIMESTONE SERIES
Upper Limestones
Edge Coal Series
Lower Limestones
Limest.
Limest.
Limest.
Limest.
Oil Shale
Limest.
Thin Coals
White Sandstones and Shales
Limest.
Red Sandstone.
Millstone Grit
Limest.
Limest.
Limest.
Limest.
Limest.
Lickar Coals
Dryburn L.
Limest.
Low Dean L.
Acre L.
Limest.
Felwell L.
Limest.
Limest.
Limest.
Limest.
Limest.
Limest.
Oxford L.
Limest.
Limest.
Oil Shale
Woodend Limestone
Dun Limestone
Scremerston Coal Series
Thin Limestones
Fell Sandstone
Tuedian Beds
Millstone Grit
Cherty Limestone
Main L.
Underset L.
Little L.
Fossil L.
Middle L.
Simonstone L.
Hardraw L.
Scar or Mountain Limestone Series
Millstone Grit
Shale
Main L. or 12 Fathom
Middle L.
Simonstone L.
Hardraw L.
Great Scar Limestone
Basal Conglomerate
Silurian Rocks
YOREDALE ROCKS



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Melmerby Scar Limestone, so it is evident that the floor on which the Carboniferous rocks were deposited was a very uneven one.

The section in Weardale is very similar to that in Teesdale, except that the Lower Carboniferous rocks are not reached.

When we reach Northumberland we find that the Mountain Limestone of Ingleborough is divided by intercalations of sandstone and shale so as to resemble in character the Yoredale Series above. This was long ago pointed out by Phillips, who says:—"The principal changes, as we proceed northward, appear to happen in the lower part of the limestone group, which loses its individuality, by admitting between its beds a constantly increasing quantity of mechanical admixtures, and at length becomes a subordinate feature in a country which has the characters of a coalfield."[1] As we proceed from South to Mid-Northumberland, while the upper or Yoredale Limestones are generally persistent, the lower limestones representing the Great Scar gradually become thinner and less important, and in many cases disappear entirely, so that eventually we find that nearly all the important limestones are in the upper or Yoredale Series. The work of my colleagues on the Geological Survey, as given in the published maps, is the authority for this part of Northumberland.

For Mid-Northumberland reference may be made to the admirable memoir by the late Mr Hugh Miller on "The Geology of the Country around Otterburn and Elsdon" (1887), in which the announcement was made (see p. 5) of the identity of the Redesdale Limestone with the Dun Limestone of North Northumberland, which is the lowest marine limestone of any importance. Mr Miller and myself had many conferences on the correlation of the Lower Carboniferous rocks, and he entirely concurred in the main results embodied in this paper. In this district the next limestone above the Redesdale is called the Fourlaws, and both these limestones traced into South Northumberland are found to lie far below the true Yoredale Limestones, and they therefore are portions of the Great Scar.

The North Northumberland section, somewhat generalised, is represented in the third column where the Dryburn Limestone is the uppermost of the Yoredales. Coals occur throughout the series down to the Fell Sandstones, but are omitted generally for the sake of clearness. It will be seen that the principal limestones fall into two natural groups, in the upper of which the limestones are numerous and pretty frequent (down to the Oxford), while several hundred feet lower comes the group of

[1] Manual of Geology, p. 165 (1855).

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the Woodend and the Dun Limestones. Below these is the group containing the Scremerston Coals, 800 to 900 feet thick, in which also limestones occur, but they are always thin (from 1 to 4 feet each), and are for the most part plant-limestones of an estuarine or fresh-water character. Underlying the coals is a thick sandstone group—the Fell Sandstones—and at the bottom of the section is a portion of the Lower Carboniferous group called Tuedian Beds by the late Mr Tate, of Alnwick, on account of their being characteristically developed along the Tweed. In 1856 Mr Tate described these beds as consisting of grey, greenish, and lilac shales, sandstones, slaty sandstones sometimes calcareous, thin beds of argillaceous limestone and chert, and a few buff magnesian limestones. *Stigmaria ficoides*, *Lepidodendron*, coniferous trees, and other plants occur in some parts of the group, but there are no workable beds of coal. The fauna consists chiefly of fish remains, Modiolæ, and Entomostraca. Generally fresh-water and lacustrine conditions are indicated.[1] The thickness of this series along the River Tweed from Carham to Berwick must be between 2000 and 3000 feet, and there is no doubt that it is the equivalent of the lower part of the Calciferous Sandstone of Scotland. Sedgwick seems to have been the first to point out the true position of these rocks in the Carboniferous formation in his address to the Geological Society in 1831; and in notes supplied by him for the third edition of De la Beche's Geological Manual he expresses the opinion that the Carboniferous Red Sandstone of the Tweed is superior to the Old Red Sandstone, and is about of the age of the Great Scar Limestone of Yorkshire and Cross Fell.[2] The natural inference from this would be that the limestones above the Scremerston coals belong to the Yoredale Series, and it will be seen that this is so far true that *most* of the marine limestones belong to that series, viz. those from the Dryburn to the Oxford inclusive. This set of beds is thinner altogether here than in Wensleydale, but the difference is principally in the limestones, which in Wensleydale amount to about 300 feet, while in Northumberland they are not much more than half that thickness.

Among the sandstones and shales that occur between the Oxford and the Woodend Limestones, there is a marked band of oil shale which is very constant in North Northumberland. It contains remains of fishes, plants, and Ostracoda, and will be met with again in the Scottish section.

In the Northumberland section, No. 1 Limestone is the Dryburn Limestone of Lowick and the Ebb's Snook Limestone of

[1] Proc. Berwickshire Nat. Field Club, vol. iv. p. 151.
[2] De la Beche, Geological Manual, 1833, pp. 391, 392.

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Beadnell, and is called further south in Northumberland the Ten-Yard Limestone. It is the Main or Twelve-Fathom Limestone of Wensleydale and Swaledale, the Great Limestone of Teesdale and Weardale, and is the uppermost member of Phillips' Yoredale Series.

No. 2 Limestone is called at Lowick the Low Dean, and at Scremerston the Sandbanks Limestone, while generally in Mid-Northumberland it receives the name of the Eight-Yard Limestone. It is called in North-West Yorkshire the Underset Limestone, and in Teesdale and Weardale the Four-Fathom.

No. 3 Limestone is the Acre Limestone of Lowick, where it is also sometimes called the Dunstone (which name must not, however, be confounded with the Dun Limestone, the lowest of the marine limestones). Further south it receives the name of the Six-Yard Stone, and in Weardale and Teesdale it is called the Three-Yard. It is the Little Limestone, 12 feet thick, in the Wensleydale section.

No. 4 Limestone is the Eelwell of Lowick and the Main Limestone of Beadnell and North Sunderland, and farther south in Northumberland it is called the Nine-Yard. In Weardale and Teesdale it is the Five-Yard, and in Swaledale it goes by the name of the Third Set of Lime. It is the 'Fossil' Lime of Wensleydale.

Now it is these four limestones, with the intermediate strata, that form the group of limestones at Cat Craig, near Dunbar, which is the lower division of the Carboniferous Limestone Series of Scotland, and therefore these marine limestones of Scotland represent only the upper part of the Yoredale Series of Phillips.

The limestones numbered one to four have been traced almost continuously for nearly 100 miles, and we are certain of their identity, but the limestones below these have not been so traced, and there is some uncertainty about their exact equivalents. It seems most probable, however, that the six comparatively thin limestones, from 5 to 10 feet each, between the Eelwell and the Oxford, represent the Scar, Cockleshell, Singlepost, and Tyne-bottom Limestones of Weardale and Teesdale, and that the Oxford is on the horizon of the Hardraw Scar, or lowest bed of Phillips' Yoredale Series of Limestones. This much is certain, that the Woodend and the Dun Limestones are far below this horizon, and represent portions of the Mountain Limestone or Great Scar Limestone of Ingleborough. The Woodend is called in the Alnwick district the Hobberlaw Limestone, and in the Otterburn and Redesdale districts the Fourlaws Limestone, while the Dun is identical with the Redesdale Limestone. In Scotland generally these marine limestones below the Eelwell

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are represented by the estuarine Calciferous Sandstone Series. We have, however, a narrow strip of Lower Carboniferous rocks some six miles in length north of the Tweed, along the coast between Berwick and Burnmouth, and here most of the beds below the Eelwell can be observed, though the section near Berwick is a good deal faulted. Between the pier and the Fisherman's Haven the Eelwell, repeated by faults and folds, occurs four times over, the Oxford then is faulted against it, and in the area bounded by faults at the Bay of the Burgess' Cove occurs a set of beds of Tuedian-like aspect on the Oil Shale horizon. Northwards from this is a pretty continuous section from the thick sandstone above the Woodend Limestone down to the genuine Tuedians, which, with a steep reversed dip, are faulted against the Silurian rocks at Burnmouth. The Woodend and the Dun Limestones are thinner here than they are generally in Northumberland. The Dun or Lamberton Limestone may be followed along the coast for nearly three miles, and below it are found some at least of the Scremerston Coals, which were formerly worked at Lamberton, but were found to be poor and thin in comparison with the same seams south of the Tweed. It is, however, probable that a fault throws out the greater part of the Scremerston Coal Series on this coast, as only the upper beds of the Series can be recognised.

About 12 miles to the north-west, in a direct line from Burnmouth, Lower Carboniferous rocks are found on the coast of Berwickshire, opposite Cockburnspath. We can recognise here in the white sandstones, interstratified with shales and with several thin and poor seams of coal, the representatives of the Scremerston Coal Series; the group of the Dun and Woodend Limestones is represented by a marine limestone in Cove Harbour, and in the next bay to the westward, immediately under the hamlet of Cove, occurs our well-marked band of oil shale. So far the section on this coast is very clear, but now the rocks which have been dipping steeply north or north-west flatten or undulate, though there seems to be a generally ascending series all along the coast to near Dunbar. Opposite Linkhead, 34 miles from Edinburgh, there is found an impure encrinital limestone, which probably represents the Oxford. It thus appears that nearly all the lower limestones are dying out one after the other as we proceed westward, and at Skateraw most of the thin limestones between the Oxford and the Eelwell have disappeared, while at Cat Craig the lowest limestone is the Eelwell itself. My colleague Mr Bennie, who has collected extensively both from the Acre Limestone of Lowick and from the second limestone (counting from below) at Cat Craig, has come independently to the conclusion that these limestones are the same, because they contain a similar assemblage of fossils.

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As all the rocks below the group of marine limestones at Dunbar have been classed as Calciferous Sandstones, it is now clear that the latter include representatives in time of the lower half of the Yoredale Rocks and the whole of the Mountain Limestone; and possibly the lowest part is older than the Scar Limestone of Ingleborough. But however this may be, it is clear that the Calciferous Sandstone of Scotland includes in its upper part beds of about 1000 feet in thickness, which in Northumberland are classed with the Limestone Series.

The upper part of the Scottish sectional column, viz., that called Carboniferous Limestone Series, is copied from that given by Mr Howell on p. 73 of the Survey Memoir on the geology of the neighbourhood of Edinburgh, and it represents the Edge Coals of the Midlothian Coalfield. Here we have a great development of coal-seams above the uppermost Yoredale Limestone, and higher up three thin marine limestones also accompanied by coal-seams. We have undoubtedly in Northumberland the equivalents of these upper limestones, also associated with workable coals, which, however, have been omitted from the Northumberland tables; lower down we have, close together, three or four coals which have been worked at Lickar, near Lowick; elsewhere in Northumberland these coals are known as Little Limestone Coals. It seems pretty clear, then, that the Edge Coal Series of Midlothian is but an extraordinary development of these Lickar Coals. Even the total thickness of the beds in the Scottish section, some 1300 feet from the lower limestones up to the Millstone Grit, can be matched in some parts of Northumberland. In Wensleydale this series is represented by a peculiar set of cherts, cherty limestones, etc., which cannot here be described, while on Ingleborough a mass of shale occupies this horizon. The term Yoredale was by the Geological Survey extended so as to include these beds, but they were classed with the Millstone Grit by Phillips, though sometimes he seems to have included a portion of them in his Yoredale Series.

It will thus appear how far from the truth was the old view that the Carboniferous Limestone Series of Scotland represents both the Yoredale Rocks and the Mountain Limestone of England, and that the Calciferous Sandstone is older than the Mountain Limestone. The newer reading, that the Scottish Limestone Series is the equivalent of the Yoredale Beds, and the Calciferous Sandstone of the Mountain Limestone, is a nearer approximation to the truth, but is still far from being correct, especially as it has been shown that the greater part of the Scottish Carboniferous Limestone Series, including the upper limestones and the whole of the Edge Coal Series, lies above the position of the Yoredale Beds of Phillips.

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L.—*On the Genera Psilophyton, Lycopodites, Zosterophyllum, and Parka decipiens of the Old Red Sandstone of Scotland. Their Affinities and Distribution.* By JAMES REID and PETER MACNAIR. (Plates XXI. and XXII.)

(Read 17th February 1898.)

FOR many years the flora of the Old Red Sandstone appears to have been much misunderstood. On the one hand, we find Psilophyton —a terrestrial plant—referred by the older geologists to the Algæ; while on the other, the more recently established genus Zosterophyllum, of aquatic origin, has been regarded by some palæobotanists *as a species of Psilophyton.* Again, Lycopodites of the Caithness flags has been identified with Psilophyton of the Lower Old Red Sandstone of Midland Scotland, though, strange to relate, not a trace of Lycopodites has been met with in the latter rocks. Parka has also been variously regarded by geologists as the fructification of a plant, and the egg-packets of molluscs and crustaceans. As the result, however, of exhaustive microscopical examinations made by Sir William Dawson and Professor Penhallow, we now know that Parka decipiens is a plant, possessing a creeping rhizome, narrow linear leaves, and sporocarp containing spores and prothalli. The recent discovery of sessile fruit in Lycopodites also confirms Salter's determination (of 1858), with regard to the distinctive character of this genus.

Parka is perhaps one of the earliest known plants of the Old Red Sandstone of Scotland. In 1831 Dr Fleming referred to it as occurring in association with *grassy-looking leaves,* and compared it with the fruit of Juncus or Sparganium,[1] while somewhat later, Hugh Miller figured and described some plant-remains from the Old Red Sandstone of Cromarty as fucoids.[2] Six figures are given in plate vii. of Miller's "Old Red Sandstone," five representing Psilophyton and *one Lycopodites.* These figures are apparently reproduced in subsequent editions of this work. We observe them in the fourth edition (1850), and in the twenty-fourth edition (1884). Mr Carruthers, as we shall presently see, refers these figures (*including Lycopodites*) to Dawson's genus Psilophyton. With regard to the plants of the Forfarshire flags, and the Psilophyton beds of Perthshire, we find Nicol quoting

[1] *Cheek's Edinburgh Journal*, p. 86, 1831.
[2] "Old Red Sandstone" (1841), p. 100.

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ZOSTEROPHYLLUM MYRETONIANUM, PEN.

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as follows: "A fine grained, bright grey sandstone prevails from the Ericht west by Coupar-Grange, Rosemount and Logie Almond. It contains numerous carbonaceous impressions, *differing, however, from those* of the grey sandstones south of the Sidlaws."[1] In 1858 Salter determined a characteristic plant of the Caithness flags as Lycopodites Milleri.[2] Mr Carruthers, however, dissents from this determination, and identifies this genus—as before mentioned—with Dawson's Psilophyton.

He remarks as follows: "Six fragments are represented on plate vii. of that work (Miller's "Old Red Sandstone," 1841). They are obviously portions of the plants to which Dr Dawson long after gave the name Psilophyton.... This plant, which figured as a fucoid in 1841 (Miller's "Old Red Sandstone"), is certainly the same as that to which Göppert in 1847 gave the name Haliserites dechenianus." Referring to Dawson's Psilophyton, he states: "The species named P. princeps . . . repeatedly branched dichotomously, with the tips sometimes rolled up in a circinate manner. The long, slender leaf-bearing branches of this *Canadian plant* indicate a *different species* from the *Scottish plant*, but in other respects the plants agree."[3]

It will be seen that this author, by assuming that Lycopodites possessed the circinate form of branching, and the fruit of Psilophyton, identifies the former with the latter as the same genus. We have, however, to point out that no circinate branching or fruit, up to this date, occurred in Lycopodites. The fruit of the latter is a more recent discovery, and the fact of its being *sessile* and *globular*—whilst in Psilophyton the fruit consists of *terminal oval spore-cases*—clearly indicates that in the former and the latter we find plants generically distinct.[4]

In 1859 Sir William Dawson refers to his discovery of Psilophyton in the Gaspé sandstones, while in 1871 he more fully describes the plant as possessing rhizomata, stems, branches, internal structure and fruit in a very perfect state of preservation,[5] thus revealing for the first time the true character of this genus.

Since this date renewed attention appears to have been directed towards the plants of the Old Red Sandstone of Scotland, which still continues.

Dawson describes Psilophyton princeps as follows: "Stems branching dichotomously, and covered with interrupted ridges, leaves rudimentary, or short, rigid, and pointed, . . . Young

[1] Guide to the Geology of Scotland, pp. 118, 119 (1844).
[2] *Quart. Journ. Geol. Soc.*, vol. xiv. p. 75, 1858.
[3] *Journal of Botany*, 1873.
[4] Plate xxi., figs. 1, 4, 5.
[5] *Quart. Journ. Geol. Soc.*, vol. xv. pp. 478, 481 (1859); and Rept. Geol. Surv. of Canada, pp. 37, 39 (1871).

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branches circinate . . . Internal structure—an axis of scalariform vessels, surrounded by a cylinder of parenchymatous cells, and by an outer cylinder of elongated woody cells. Fructification consisting of naked oval spore-cases, borne usually in pairs on slender, curved pedicels, either lateral or terminal."

With regard to Psilophyton robustius: "The habit of growth at once distinguishes this species, as well as the smooth dotted surface, *the absence* of *distinct leaves*, and its crowded clusters of spore-cases." [1]

The genus Psilophyton dechenianum (first established by Mr Carruthers), in our opinion, and apparently in that of geologists generally, contains *several distinct genera* of plants. Its author describes it in the following terms:—

"The only British species may be thus characterised: Psilophyton dechenianum (Carr.). Lower branches short and frequently branching, giving the plant an oblong circumscription.

1841. Fucoid. Hugh Miller (Lycopodites ?).
1847. Haliserites dechenianus. Göpp.
1857. Lepidodendron nothum. Salter (non ung.).
Lycopodites Milleri. Salter." [2]

In Mr Kidston's Psilophyton dechinianus (Göpp sp.) the plants forming P. dechenianum (Carr.) are included, while Dawson's P. robustius and numerous continental plants are added to the list. We observe that Miller's Fucoid, 1841 (Carr.), is post-dated by this author to 1857 and 1865.[3]

We have elsewhere dealt somewhat exhaustively with the genera Psilophyton and Lycopodites, to which we refer.[4] A few salient points, however, bearing upon the subject may be here adverted to.

Messrs Carruthers [5] and Kidston [6] refer Psilophyton princeps to a Canadian species, but in Miller's "Old Red Sandstone" (plate vii., fig. 3) the slender figure showing circinate branching is certainly not P. robustius, which is many times larger. It is, therefore, referable to P. princeps. Yet these authors, while rejecting this species from the Old Red Sandstone of Scotland on the one hand, restore it on the other.

Sir William Dawson is, perhaps, equally well-qualified to express an opinion, and with regard to a suite of specimens of Psilophyton (from the Murthly sandstones) we submitted to him in 1889, he remarks:

[1] Rept. Geol. Surv. of Canada, pp. 37, 39, 1871.
[2] *Journal of Botany*, 1873.
[3] Cat. Brit. Mus., Palæo. plants, pp. 232, 233 (1886).
[4] Trans. Geol. Soc. of Glasgow, 1896.
[5] *Journal of Botany*, 1873.
[6] Cat. Brit. Mus., Palæo. plants, p. 232 (1886).

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"*Psilophyton princeps* predominates as in Gaspé. . . . P. robustius is less abundant, and Arthrostigma gracile is represented by some portions of stems. On the whole the assemblage is exactly those of the lower division of the Gaspé sandstones."[1]

We have compared P. princeps of the *Murthly sandstones* with P. princeps from *Campbellton, N. Brunswick*, and find their points of structure (including the fruit) identical. It is also to be noted that P. robustius—which Kidston identifies with Lycopodites[2]—has shown no leaves, while in Lycopodites the leaves are often numerous and imbricated. Since Salter's determination of Lycopodites, this genus appears to have been generally adopted by geologists.

It is recognised by Sir William Dawson in 1871,[3] by Messrs Jack and Etheridge in 1877,[4] and by Sir A. Geikie in 1878.[5] Even Mr Kidston himself, while disputing its occurrence in the Scottish Old Red, refers to Lycopodites Richardsoni (Daw.) of the Devonian of Perry, Maine, United States.[6]

In short, we have to state that, with the exception of Messrs Carruthers' and Kidston's papers on P. dechenianum, we have not seen this so-called genus referred to in any text-book or paper on geology.

But further: "The more recent discovery of the Psilophyton beds of the Lower Old Red Sandstone of Midland Scotland, affords additional evidence in favour of the distinctive characters of Psilophyton and Lycopodites. From Rosemount, East Perthshire, to the shores of Loch Lomond, numerous exposures occur in these upper sandstones, presenting a profuse assemblage of stems, branches, and occasionally fruit of Psilophyton.[7] Were the latter and Lycopodites identical, we should be prepared to find in some of these beds evidence of the fact. But throughout the Lower Old Red Sandstone of Central Scotland, *Lycopodites is conspicuous by its absence.*"[8] It is also to be noted, that in the lower, middle and upper sandstones of Gaspé and New Brunswick, Psilophyton prevails, but *Lycopodites is absent.*[9]

We have referred to the fructification of Lycopodites, which occurs in a specimen we obtained from the Caithness flags in 1891. It consists of sessile, globular sporangia, thus showing that P. dechenianum (Carr. and Kidston) is founded upon *at least two plants generically distinct.*

[1] *Nature*, April 10, 1890. [2] Cat. Brit. Mus., Palæo. plants, p. 232, 1886.
[3] Rept. Geol. Surv. of Canada, 1871, p. 34.
[4] *Quart. Journ. Geol. Soc.* (1877), p. 216.
[5] "The Old Red Sandstone of Western Europe," p. 402 (1878).
[6] Cat. Brit. Mus., Palæo. plants, p. 231 (1886).
[7] See "Text-book of Geology," Sir A. Geikie, p. 708 (1882).
[8] Trans. Geol. Soc. Glasgow, 1896.
[9] "The Geological History of Plants," Sir Wm. Dawson, pp. 279, 280 (1888).

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Professor Penhallow says of this fertile specimen of Lycopodites: "The specimen is a carbonised fertile stem 8 c.m. long, and 6 m.m. wide, showing a short branch at the base. The leaves are narrowly lanceolate, acute and somewhat spreading. The basal articulation of the scales is obscure, but among these organs, sometimes strictly basal, or again scattered irregularly over the entire remains, are carbonised sporangia 1 m.m. in diameter. The indications of the specimen point to a spiral arrangement of the leaves. The whole aspect of the plant is strongly suggestive of Lycopodium selago, both in its general form and in the way the fruit is produced."

"The description is: stems branching, leaves disposed spirally, narrowly lanceolate, acute, 5 m.m. long, 1 m.m. broad at the base; sporangia globular, 1 m.m. broad."[1]

We pass to a consideration of Zosterophyllum myretonianum (Penh.). This plant is usually associated with Parka decipiens in the Forfarshire flags. The latter, however, shows non-dichotomous leaves of two dimensions. In Parka Flem. they reach 1 c.m. in breadth, while in Parka media and P. minor they are about 2 m.m. broad. We shall however discuss this genus more fully in the concluding part of this paper. Prof. Penhallow describes Zosterophyllum as "Aquatic plants with creeping stems, from which arise narrow dichotomous branches and narrow linear leaves of the aspect of Zostera. Fruit are ovoid or spherical sporangium (?) produced with short pedicels without subtending tracts, from a single axis, the whole forming a loose spike."[2]

As we have seen, the *grassy-looking leaves* referred to by Dr Fleming in 1831 indicate Zosterophyllum. Nicol in 1844 appears to have observed the characteristics of Zosterophyllum and also of Psilophyton of the Perthshire sandstones, while Hugh Miller[3] notes a peculiar structure (anastomosis) detected by Dr Fleming in this genus, which places it in an unique position among the plants of the Old Red Sandstone of Scotland. We have observed this structure in Zosterophyllum—uniting contiguous leaves altogether, as Miller remarks, like the Siamese twins. In speaking of the plants of the Forfarshire flags, Miller says:—"I observed in particular one large bunch of ribbon-like leaflets converging into a short stem, so that the whole resembled a scourge of cords."[4] In 1882 Sir A. Geikie also refers to the grass-like plants of the Forfarshire rocks.[5] These

[1] *Canadian Record of Science*, p. 9, 1892.
[2] *Canadian Record of Science*, p. 12, 1892.
[3] "The Test. of the Rocks," p. 446 (1857).
[4] "Old Red Sandstone," 4th ed., p. 188 (1850).
[5] "Text-book of Geology," p. 714 (1882).

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descriptions—grass-like plants and ribbon-like leaflets—exactly agree with the bunch of Zosterophyllum shown in the specimen on the table before us.[1] If we were to suppose this bunch of the plant broken into fragments and scattered over the beds in which Zosterophyllum is prevalent, we should find the same exactly represented by the broken fragments of plants met with in these beds. The latter show a simple bifurcation, which is also a characteristic of the parent plant.

Mr Kidston, however, notes the occurrence of Psilophyton (P. dechenianus) in association with Pterygotus in the Forfarshire rocks.[2] Before accepting this view we should require evidence as to the occurrence of *a central stem branching dichotomously*, circinate vernation, and fruit, all of which appear to be absent. We have examined numerous specimens of plants from the flags of Myreton, Duntrune, Carmyllie, and Turin Hill (localities somewhat widespread and representative), but in none of them have we discovered a central branching stem of Psilophyton.

The latter, as seen in specimens before us, shows numerous dichotomous branches, even in specimens of very small dimensions (see specimens from Campbellton, N. Brunswick, Caithness, and Murthly).

Zosterophyllum then appears to be generically distinct from Psilophyton. The structure of its leaves is in marked contrast to that of the stems and branches of the latter plant. Prof. Penhallow, in referring to the leaves of Zosterophyllum, remarks: "linear leaves often showing fine parallel veining.[3] In Dawson's description of Cordaites augustifolia, which he identifies with Zosterophyllum, he states: "leaves linear and much elongated, with delicate *equal parallel nervures*."[4]

This equal parallel veining observable in the leaves of Zosterophyllum presents a structure widely different from the somewhat bold *interrupted ridging* often met with in the stems and branches of Psilophyton.

Closely surrounded by leaves of Zosterophyllum, Prof. Penhallow discovered a fruiting spike. Another of these spikes is before us. Unattached fruit bodies are also prevalent in the Forfarshire flags.[5] These fruiting spikes and fruit bodies show no resemblance to the fructification of Parka, or even to the spore-cases of Psilophyton; they have therefore been referred by Prof. Penhallow to Zosterophyllum.

Some years ago we discovered in the Myreton shales several

[1] Plate xxii., fig. 1. [2] Cat. Brit. Mus., Palæo. plants, p. 234 (1886).
[3] *Canadian Record of Science*, p. 9, 1892.
[4] Rept. Geol. Surv. of Canada, p. 44, 1871.
[5] *Canadian Record of Science*, p. 11, 1892.

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minute, globular, carbonaceous bodies, rather more than ·50 m.m. in diameter. They show no appearance of structure, but we think they may probably represent *the sporangia* of Zosterophyllum.

Summary.—We may regard Psilophyton as distinguished from Lycopodites by its terminal spore-cases, rigid structure, and circinate branching. Lycopodites, on the other hand, appears to have possessed a somewhat herbaceous structure and recumbent habit of growth, whilst its sessile fruit undoubtedly differentiates the plant from Psilophyton and Lepidodendron, with which it has mistakenly been identified.

Zosterophyllum, in its narrow linear leaves, showing *fine equal parallel veining*, its creeping rhizome, anastomose structure, and globular fruit, certainly indicates a genus distinct from Psilophyton, presenting all the characteristics of an aquatic plant, apparently allied to Parka decipiens of the same beds.

Turning now to give a brief description of Parka decipiens, it will be remembered that this remarkable fossil was first discovered by Dr Fleming at Parkhill near Newburgh, Fife, from which locality it derives its generic name. Dr Fleming afterwards described it in *Cheek's Edinburgh Magazine* for 1831,[1] there ascribing to it a vegetable origin and considering it to be the "conglobate panicles of extinct species of the genus Juncus or Sparganium."

Since the time of Fleming up to the present day, Parka has attracted the attention of many of our leading geologists, as Lyell, Miller, Page, Powrie, Peach, Geikie and others. It was reserved, however, for Sir William Dawson and Professor Penhallow to reveal the true nature and relationships of the fossil, which they did in a paper contributed to the Royal Society of Canada,[2] in the year 1892, and in which, we submit, they placed the vegetable origin of Parka beyond dispute by the discovery of a mass of evidence to which we shall presently refer, and for a detailed account of which we would refer the reader either to the original papers by these authors, or to a paper published in the Transactions of the Glasgow Geological Society, by the present writers and Mr W. Graham of Rescobie, for the year 1897.[3] After the discovery of Parka by Dr Fleming, various opinions came to be held as to the exact nature of the fossil by those geologists already mentioned, some believing it to be the fruit of a flowering plant, while others, recognising its common association in the same beds with such Eurypterid crustaceans as Pterygotus, considered it to be the egg-packets of these animals,

[1] *Cheek's Edinburgh Magazine*, 1831, p. 86.
[2] Transactions of the Royal Society of Canada, vol. ix. (1892), sec. 4, p. 3.
[3] Trans. Geol. Soc. of Glasgow, vol. xi. p. 105, 1897.

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a view which latterly was generally held to be correct, and became universally adopted in geological and palæontological text-books. The publication of these papers by Sir William Dawson and Professor Penhallow, in our opinion, has placed the vegetable origin of Parka beyond dispute, showing as they do from a mass of cumulative evidence that Parka and its associated leaves and stems are closely allied to our modern rhizocarpean forms. The following being their description of the genus Parka Fleming: aquatic plants with creeping rugose stems, linear leaves and sessile sporocarps bearing three kinds of sporangia. Sporangia 2 m.m. in diameter, macrospores 40 m.m., microspores 15 m.m.[1]

Parka decipiens, or rather that part of the plant which is now recognised as its sporocarp, and to which the name was originally given by Fleming, consists of oval or circular masses of disc-shaped bodies, sometimes preserved as a black carbonaceous substance, and at others as a mere pseudomorph of iron from which all trace of its original vegetable structure has been removed. Professor Penhallow recognises three forms of the sporocarp, one of which he refers to the species, while the other two are recognised as varieties—these being principally founded on differences of form and size, the varieties being named Parka media and Parka minor. Their dimensions are as follows: Parka decipiens, 3·5 × 5·5 c.m.; P. media, 13 × 20 m.m.; P. minor, 6 × 16 m.m. It may here be noted that the sporocarp of Parka shows the internal grooving possessed by the modern rhizocarpeæ. It has been suggested by some that the Parka discs or sporangia are of the nature of sporocarps attached to an oval, striated leaf-like body. But the discovery by us of a sporocarp from the shales of Myreton, which, splitting in two, showed on one side the usual cluster of discs, and on the other the impressions only, has led us to the conclusion that the sporangia have been enclosed in a sac or covering, of which the grooved portion to which the discs are usually attached forms the one side, while that with the hexagonal or circular impressions only forms the other, the two taken together completing the indusium.

It is a singular fact that amongst the many hundreds of specimens of Parka sporocarps, which have been found in these beds of Forfarshire during the last seventy years, not one instance has yet been recorded of these bodies having been found in actual organic union with any of the other plant remains found in the same beds; as we shall presently see there is abundant evidence in the sporocarp itself, not only to prove its vegetable origin, but also to give us a clue as to its real affinities. But why this complete isolation of the sporocarp

[1] Transactions of the Royal Society of Canada, vol. ix. (1892), sec. 4, p. 16.

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from the rest of the plant? Those who have seen the fragmentary condition in which these plant remains occur, will the more easily understand this isolation of the sporocarp from the rest of the plant.

In not a few instances we have found evidence of what appears to be a sporocarp set upon a stalk, but it is often difficult to determine whether the apparent stalk and sporocarp are in actual organic union, or are only deceptively so. It will also be recollected that in the later editions of "The Old Red Sandstone"[1] there is a figure given of Parka, apparently in connection with a stalk, from the collection of Lord Kinnaird.

Intimately associated with these sporocarps and scattered over the same slabs are found stems and leaves, which we venture to think have been correctly associated by Sir William Dawson and Professor Penhallow with the sporocarp just described as part of the same plant. The stems of Parka decipiens are somewhat large and of a rugose character, the leaves being 1 c.m. broad, with rounded terminations. The stems of Parka media and Parka minor are of a smaller size, and the leaves measure about 2 m.m. in breadth, closely resembling the rachis of Pilularia. One of our specimens from the flags of Turin Hill distinctly shows a number of stumps of leaves proceeding from a creeping rhizome.

It is when the Parka discs or sporangia are submitted to a microscopic examination that the most conclusive evidence bearing upon their vegetable origin and affinities is to be found. But before proceeding to discuss this we might briefly indicate the method employed in the preparation of the discs for microscopic examination. If a few of the Parka discs be separated from the matrix, placed in a test tube with nitric acid, and then held over a flame and boiled out, it will be found in some cases that the outer black carbonaceous covering of the disc has disappeared and revealed an inner amber-coloured layer. If these discs be examined at this stage, or even without having been boiled in the acid, they will be seen to show upon their surface a beautiful hexagonal cellular areolation, first noticed by Sir Wm. Dawson, and of which he says: "In comparing this with the surface of sporocarps of Protosalvonia from Ohio and Brazil I found the structures perfectly similar. This was so far an indication of vegetable affinity, as I know of no crustacean or molluscan showing such cellular areolation."[2]

If those discs which have become more or less transparent in the process of boiling, be then broken up in water and examined under the microscope, there will be found amongst the broken-

[1] "Old Red Sandstone," p. 277 and plate xiii.
[2] Trans. Royal Society of Canada, vol. ix. p. 6.

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up fragments numerous oval-shaped bodies, which have been described by Prof. Penhallow in the paper which we have already cited, to be of the nature of spores, and similar in every respect to the microspores and macrospores of our living rhizocarpeæ That they are of the nature of spores we do not think there can be any doubt. We have shown them to several botanical experts and their similarity is at once admitted.

Prof. Penhallow further describes the occurrence in his slides of aggregations of cells around a central carbonised mass. These he at first mistook for the walls of empty sporangia, but a further examination has shown that they are more likely to be of the nature of prothalli. In a series of these aggregations of cells they show what appears to be different stages in development. In the earlier stages of growth from the spore they are spherical, while in the later they are flat and thalloid.

In several of our slides we have found evidence of a rectangular marking upon the spores, which may represent the hilum or scar of attachment. Sir Wm. Dawson notes the occurrence of the triangular mark of Isoetes upon some of the spores, which may be the same as those markings we have just mentioned.

Such, then, is a brief recapitulation of the evidence upon which the vegetable origin and rhizocarpean affinities of Parka has been based. Some have cast doubts upon the value of the microscopical evidence, and pointed out the exceeding fragmentary conditions in which the different parts of the supposed genus occur. Regarding the objections to the microscopical evidence, we would merely again repeat that we have examined a large number of slides, and have shown them to several botanical experts, who have agreed that the evidence for the existence of spores and prothalli within the Parka discs is of such a nature as to be perfectly conclusive to their own minds. As to the fragmentary nature of the "supposed" genus, and the fact that the separate parts are never to be found in actual organic union, we would merely point out that plants having the whole of their parts in actual organic union are exceedingly scarce in the geological formations. And if palæobotanists were to admit only such species as those whose whole parts had been found in actual union we would have a very poor fossil flora indeed. The parts of Parka are not, we venture to think, in any more fragmentary conditions than many plants of carboniferous times. And it still remains for those who object to Sir Wm. Dawson and Prof. Penhallow's determinations to show us what Parka is, and if of vegetable origin to what part of the vegetable scale it is to be assigned.

Turning now in conclusion to a brief consideration of the distribution of these four genera of Old Red Sandstone plants,

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we may remark at the outset that, having already elsewhere expressed our opinions as to the physical conditions under which we think the Scottish Old Red Sandstone has been accumulated, and having there maintained the necessity of considering the Lanarkian, Caledonian, and Orcadian rocks[1] as representing three distinct and well-marked horizons, of which the Lanarkian is the oldest, the Caledonian the next, and the Orcadian the youngest in time; we have shown, in support of this view, that the petrological characters, stratigraphy and structural relationships, as seen in each of these three areas, entirely favours their formation under widely differing physical conditions, and which could not be obtained under the supposition that they represent contemporaneous basins. It may also be pointed out in passing that the evidence derived from the fish fauna of these rocks points most conclusively in the direction that these three groups of the Scottish Old Red Sandstone represent three distinct and successive horizons in geological time.

Let us now see what evidence the distribution of these four genera of Old Red Sandstone plants brings to bear upon the question. The genera Psilophyton first makes its appearance in the upper beds of the middle or Caledonian series of the Scottish Old Red Sandstone deposits, and its decorticated remains, with occasional more perfect specimens showing fruit and characteristic circinate vernation, are well known to crowd the upper sandstones stretching from Rosemount, south of Blairgowrie, through Murthly, Logiealmond, Callander, Gartmore and thence onward to the shores of the Firth of Clyde. Formerly, Psilophyton was supposed to occur upon a much lower horizon, namely, in the fossiliferous beds which underlie the volcanic zone of the Sidlaws and Ochils, and which, appearing at Balruddery, stretch north-eastward into Forfarshire. But as we have already shown at the outset of this paper, Psilophyton has never been definitely ascertained to occur upon this horizon, the broken remains of Zosterophyllum being often erroneously referred to this plant. In a paper published in the Transactions of the Glasgow Geological Society,[2] by the present authors and Mr W. Graham, we have named these two distinct horizons of plant remains as the Parka and Psilophyton zones, and for further details as to the stratigraphical relationships of which we would refer the reader. Psilophyton also occurs in the Orcadian series, specimens of the plant being found in the John o' Groats beds and in the flagstones around Thurso. As at Holburn Head, Hill of Forss and Castletown, also at Kilmister, Wick; it seems, therefore, to range from the upper sandstones in the axial beds

[1] *Geological Magazine*, vol. iii. pp. 106, 217.
[2] Trans. Geol. Soc. of Glasgow, vol. xi. p. 112.

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of Strathmore of the Caledonian series, to the highest beds of the Orcadian series as seen at John o' Groat's House. Lycopodites is only known to occur in the upper or Orcadian series, and seems to be confined to the Thurso flagstone group.

The genus Zosterophyllum is first known to appear in the Caledonian group, and in the beds which we have already mentioned as underlying the volcanic zone of the Sidlaws and the Ochils, ranging from Balruddery north-eastwards through Myreton, Carmyllie, Turin Hill and Glammis. Zosterophyllum also passes from the Caledonian upwards into the Orcadian group, and occurs along with Psilophyton and Lycopodites in the flagstone series of Thurso. Passing now to the genus Parka we find it has an exceedingly limited distribution in the Scottish Old Red Sandstone, being confined to the Caledonian group, and to these beds underlying the volcanic zone of the Sidlaws and Ochils having a similar geographical range to Zosterophyllum. In a paper in the Transactions of the Geological Society of Edinburgh,[1] by Mr R. Etheridge, Junior, this author refers to a specimen of Parka decipiens in the collection of Mr Henderson, from the Upper Silurian of the Pentland Hills. It has also been recorded from the Kidderminster beds of England, so that Parka may be considered as characteristic of the Upper Silurian and Lower Old Red Sandstone rocks.

From this description of the distribution of these four genera of Old Red Sandstone plants, it will be seen that while Psilophyton and Zosterophyllum are common both to the Orcadian and Caledonian series, Lycopodites, on the other hand, is confined to the Orcadian series alone, while Parka may be said to be limited to the Caledonian series with the exception of the Pentland and Kidderminster specimens, which we have not seen, and of whose value in determining the geological distribution of the plant we cannot therefore speak. Regarding the value of Psilophyton in the question of the relative ages of the Orcadian and Caledonian series, it would be well to bear in mind that this genus occurs in the Lower Middle and Upper Sandstones of Gaspi and New Brunswick. Zosterophyllum seems to be common to both areas.

It is, however, when we consider the general facies of the Orcadian flora with that of the Caledonian, when we find in the Caithness flags Lycopodites and the remains of plants evidently allied to Lepidodendron and Calamites, and also ferns, shadowing forth, as it were, the coming Carboniferous flora, and none of which species are to be found in the Caledonian series; while, on the other hand, in the Caledonian group we find quite a distinct flora, having an Upper Silurian facies, such as Parka Pachytheca and Arthrostigma, none of which are known to pass

[1] Trans. Geol. Soc. of Edinburgh, vol. xi. p. 314.

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upwards into the Caithness beds; it is when we carefully weigh this evidence with that derived from the fish fauna of the two areas and their respective petrological and stratigraphical characteristics, that we are driven by the overwhelming evidence to the conclusion that they represent two distinct periods in geological time, of which the Orcadian is the younger, while the Caledonian is the older of the two areas.

DESCRIPTION OF PLATES.

Plate XXI.

Fig. 1. Zosterophyllum Myretonianum, natural size.
Fig. 2. Fruiting spike of Z. Myretonianum from Myreton.
Fig. 3. Another fruiting spike of Z. Myretonianum from Carmyllie.
Fig. 4. Anastomose structure in the leaves of Z. Myretonianum.
Fig. 5. Another example of Anastomose structure.
Fig. 6. Separate mature fruit bodies of Z. Myretonianum.

Plate XXII.

Fig. 1. Psilophyton princeps restored from a Murthly specimen, showing fruit and circinate vernation.
Fig. 2. Psilophyton robustius, stem, from a Murthly specimen.
Fig. 3. Fruit of Psilophyton princeps enlarged to natural size.
Fig. 4. Lycopodites Reidii, showing stem leaves and sporangia, from Thurso flags.
Fig. 5. Ideal section of Lycopodites Reidii, showing relationships of stem, leaves and sporangia.
Fig. 6. Sporocarp of Parka decipiens, showing the internal grooving characteristic of the rhizocarpeæ, from Myreton.
Fig. 7. Transverse section of sporocarp of Parka decipiens, showing sporangia and upper and under parts of indusium, from Myreton.

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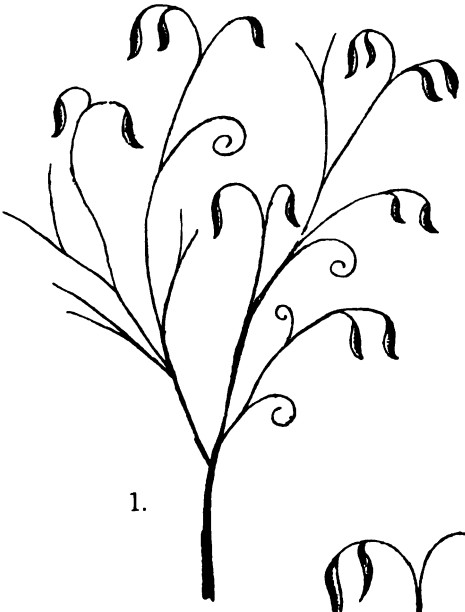

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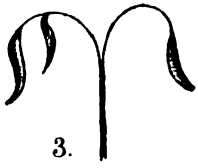

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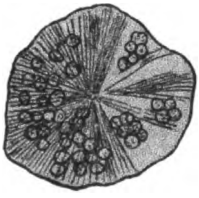

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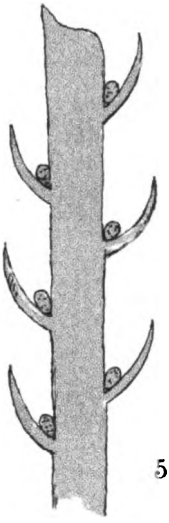

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OLD RED SANDSTONE PLANTS

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LI.—*On a Coarsely Spherulitic ("Variolitic") Basalt in Skye.*

By C. T. CLOUGH, Esq., M.A., F.G.S., and ALFRED HARKER, Esq., M.A., F.G.S., Fellow of St John's College, Cambridge. Communicated by permission of the Director-General of the Geological Survey. (Plate XXIII.)

(Read 17th March 1898.)

LAST summer, during the examination of the southern extremity of the district of Sleat, in the island of Skye, a thin basic intrusive sheet was met with, which contained spherulites of an unusually large size. Some of them are considerably larger than any yet recorded in basic rocks either in Britain or elsewhere.

In Sleat spherulites are abundant in the trachytic or andesitic, pitchstone, and granophyre dykes, and they sometimes occur in basaltic intrusions, but, except for the occurrence now to be described, no spherulites larger than boy's marbles have been noticed. In some parts of the world, however, as is well known, the spherulites in acid rocks attain a very large size. Professor J. W. Judd [1] mentions some in the granophyre of the Cuillin Hills that are nearly two and a half inches in diameter. One of us [2] has recorded some in the rhyolites of Bala age at Careg-y-defaid near Pwllheli, Carnarvonshire, which are as much as two feet in diameter. These, however, are small beside the examples noticed by Whitman Cross [3] in the rhyolite of Silver Cliff, Colorado, which are sometimes ten feet in diameter.

A certain vagueness or mystery which has always attached to the petrographical treatment of the so-called "variolites" seems to arise partly from the usually minute dimensions of the special structures in question, partly, and mainly, from the much altered character of most of the examples studied. The fullest description we have is perhaps Löwinson-Lessing's account of the rock of Jalguba [4] on Lake Onega. There the largest spherulites are only about a quarter of an inch in diameter. The largest recorded "varioles" in British examples range up to half an inch, in the rock of Roundwood, Co. Wicklow, as described by Sollas. In the case here described the diameter of the individual spherulitic growths is often as

[1] Q.J.G.S., vol. xlix. p. 187, 1893.
[2] "Bala Volc. Rocks of Caernarv." (1889), p. 35.
[3] Proc. Colo. Sci. Soc., 1890, p. 275; 17th Ann. Rep. U.S. Geol. Sur., Part II., p. 298, Pl. xxviii., 1896.
[4] Tscherm. Min. Petr. Mitth. (N.S.), vol. vi. pp. 281-300, Pl. iv., 1885.

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much as two and a half or three inches. Further, the rock is practically in its pristine condition. For these reasons the description given below may be of interest for purposes of comparison.

Basaltic rocks exhibiting spherulitic or variolitic structures, perfect or imperfect, and of several distinct types, have already been described from different localities among the Tertiary rocks of the British Isles; viz., by Judd and Cole from the Beal [1] in Skye; by Cole from the Quiraing in Skye, from Ardtun in Mull,[2] and from Tollymore, Annalong,[3] and Dunmore Head [4] in County Down; by the late Professor Heddle from Loch Screden in Mull.[5] From Palæozoic or presumably Palæozoic rocks examples have been studied by Blake [6] and Cole [7] from Careg Gwladys in Anglesey; by Groom from Carrock Fell [8]; by Miss Raisin from various localities in the Lleyn district of Caernarvonshire [9]; and by Sollas from Roundwood, Co. Wicklow [10]; some of these having many points in common with the rock now described from Camas Daraich. Andesites with variolitic structure have been noted from Beinn Shiant in Ardnamurchan,[11] Aran Benllyn near Bala, Carrock Fell,[12] and the Fishguard district.[13]

The sheet to be described is exposed near high water mark near the centre of the bay of Camas Daraich, just on the E. side of the Point of Sleat (one inch sheet 61), and runs almost horizontally through a series of contorted granulitic grits or arkoses. The best exposures are a little W. of the centre of the bay, at a distance of about $\frac{5}{12}$ mile from the Point. In this locality the thickness is generally one or two feet only, and in one place the intrusion assumes a vertical dyke-like form, running almost at right angles to the ordinary outcrop, and is only from four to five inches thick. A similar sheet is seen, but more obscurely, in another locality $\frac{1}{8}$ mile N.E. of these exposures. There is an obscure area, partly of tidal sand, between the two localities, but it is probable that the sheets in both belong to the same intrusion.

[1] Q.J.G.S., vol. xxxix. p. 460, 1883.
[2] Q.J.G.S., vol. xliv. pp. 300-307, Pl. xi., 1888.
[3] Sci. Proc. Roy. Dubl. Soc., vol. vii. pp. 511-519, Pl. xxi., 1892.
[4] *Geol. Mag.*, 1894, pp. 220-222.
[5] Trans. Geol. Soc. Glasg., vol. x. pp. 84, 85, Pl. iii., 1896.
[6] Rep. Brit. Assoc. for 1888, pp. 410, 411, Pl. v., fig. 22.
[7] Sci. Proc. Roy. Dubl. Soc., vol. vii. pp. 112-120, Pl. x., 1891.
[8] Q.J.G.S., vol. xlv. pp. 298-304, Pl. xii., 1889.
[9] Q.J.G.S., vol. xlix. pp. 145-159, Pl. i., 1893.
[10] Sci. Proc. Roy. Dubl. Soc., vol. viii. pp. 94-106, 1893.
[11] Judd and Cole, *l.c.*
[12] Harker, *Geol. Mag.*, 1894, pp. 551-553; "Petrology for Students," fig. 41, 1895 and 1897.
[13] Reed, Q.J.G.S., vol. li. pp. 183-187, Pl. vi., 1895.

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In the best exposures the radiate spherulites are seen to occur in abundance throughout the entire thickness of the sheet, excepting for about an inch near the top and bottom surfaces. These thin external portions are so fine in grain that no constituents are separable by the naked eye. Just at the top surface a thin selvage, perhaps $\frac{1}{20}$ inch in thickness, of black glassy rock is seen, and this has partly weathered with a blue colour. The exact surface of contact with the country rock is not so distinctly seen near the bottom of the sheet. The spherulites are distinct in weathered rock faces, and in freshly broken hand specimens the radial feathery lines belonging to the shapes appear as bright silk-like threads, which at once attract the attention, even before their methodical arrangement is made out.

In the dyke-like portion of the intrusion the spherulites are less at the distance of one inch from the side than further in, and it is probable that the general rule[1] of decrease in size as the surface of the intrusion is approached obtains also in the rest of the intrusion. Yet, in one place, at a distance of only two inches below the top surface of the sheet, an oval spherulite, exposed on a rock face parallel to the surface, was observed, which had a longer diameter of three and a half inches. No spherulite appreciably larger than this was anywhere noticed, and it seemed as if the general size of the spherulites was as large at this distance from the surface as in the middle.

The forms of the spherulites are various. Many of them are bounded by plane surfaces on one or more sides, and so appear in sections as polygonal or partially polygonal figures. In the forms with rounded or curved surfaces, oval sections are more common than circular sections, but the differences between the longer and shorter diameters are usually not great. In a few cases, however, the sections are more elongate, and we get an approach to "axiolites." It has not been noticed that there is any general difference in shape between the sections exposed in rock faces parallel to the cooling surfaces and those in rock faces perpendicular to these surfaces.

Where the spherulites are edged by plane surfaces, we always find that these surfaces are in close contact with the sides of other spherulites. In the portion of the intrusion which shows distinct spherulites to the eye there are small areas here and there in which we can discern no radiate structure. These areas are more or less evenly mixed among the spherulites, and are perhaps equal to the spherulites in extent. When two

[1] This rule is shown excellently in the trachytic or andesitic dykes of Sleat, and also in those of the Cowal district of Argyllshire. See "Geology of Cowal," p. 169.

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spherulites are close together without any such area between them, their surface of contact becomes a plane, and when a spherulite is in contact with other spherulites on all sides,—as is the case quite commonly,—all the sides of this spherulite are plane surfaces, and they have polygonal outlines. When a spherulite is bound on one side by an area which shows no radiate structure, its boundary on this side is a curved surface, even while the other sides which abut against other spherulites are planes. It seems probable, therefore, that we may regard the spherulites with plane surfaces as having been formed by the growth into close contact of forms which had originally rounded surfaces.

The sheet is crossed by joints parallel to the cooling surfaces and also by others which cut the rock into columns perpendicular to these surfaces. The spherulites are crossed by both these sets.

A specimen which was taken two inches below the top surface of the sheet, and itself showed spherulitic structure, was determined, by Walker's balance, to have a specific gravity of 2·92, and another specimen gave the same figure. This high density indicates a thoroughly basic composition for the rock.

Four specimens were selected for closer examination, and thin slices were prepared from them. Three of the specimens [7845, 7947, 7948] are dense rocks of very dark grey or almost black colour on a fresh fracture, but with the peculiar sheen resulting from the presence of innumerable slender fibres. Further inspection shows that these fibres have a radiate disposition about certain centres, forming spherulitic growths with diameters ranging from 1½ to 3 inches. The remaining specimen [7846], taken nearer to the surface of the intrusion, is rather blacker and more compact, with a certain lustre suggestive of some amount of fresh glassy base. Here the spherulites are smaller, ranging from ¼ to ½ inch in diameter. In all cases the spherulites are closely crowded, for the most part impinging upon one another, though one specimen shows small interspaces without evident radiate structure. The polygonal outlines of the spherulites, resulting from the manner in which they are crowded together, are well shown on the smooth-cut faces or in the slices as held up to the light (fig. 1).

FIG. 1.

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The first three slices are sufficiently alike to be described together. They are seen to consist to a large extent of slender divergent fibres which are clear and colourless, with low interference-tints, and are evidently of felspar. From some rather wide extinction-angles measured, it seems to be a rather basic labradorite, but the overlapping of the fibres renders any precise optical tests difficult of application, and most of the extinction-angles were quite low. This anomaly, arising from the way in which the thin nearly parallel fibres overlie one another in the thickness of the slice, is observed in other variolitic basalts. Thus in the Jalguba rock, already referred to, Löwinson-Lessing[1] found extinction-angles up to 5° only, although analyses of the rock prove that the felspar must be a labradorite. A like inference might be drawn in our own case from the specific gravity of the rock.

In addition to the felspar which forms the bulk of the rock, the slices show olivine, augite, magnetite, and some interstitial matter. Olivine is always abundant in numerous crystals which range from ·002 to ·005 inch or more, and, though minute, are of notably greater dimensions than the thickness of the felspar fibres. They interrupt the latter in such a fashion as to show that they are of earlier crystallization than the spherulites, but in no case have they been seen to serve as nuclei for the spherulitic growths. The olivine is clear and colourless except at the margin of each crystal, which is beginning to pass into a pale green serpentine. This change seems to be facilitated by a certain structure parallel to the brachypinacoid, often apparent as a faint striation parallel to the long axis of a crystal-section.

Augite has a faint yellow tinge in the slices. In those parts where the felspar is in thin parallel fibres the augite occurs in the interspaces between the fibres. Sometimes it is in granules no longer than broad, but more usually it is in pieces of considerable length, from three or four up to nine or ten times as long as the distance between adjoining fibres. We often see four or five adjoining interspaces occupied by augite pieces which are similarly oriented, as if they belonged to one individual. The augite seems, therefore, to be of later growth than the felspar fibres, and to be of the ophitic character so common in the intrusive Tertiary basalts of Scotland. The areas in which the augite pieces extinguish simultaneously vary considerably in size. On the average they are perhaps about the same size as the olivines, but are more variable in occurrence. Not uncommonly there are various augite areas with different orientation in close contact.

[1] *Loc. cit.* p. 292.

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Magnetite is always well represented, but is in smaller crystals than the olivines or augites. It is partly in little octohedra, some of which lie across the felspar fibres, but in other places it lies between these fibres in pieces which have their longest sides in contact with them, as if the margins of the pieces had been to a large extent determined by pre-existing fibres. It also occurs as small inclusions in the augite.

The interstitial matter in these slices is not in large quantity. In the interspaces between the felspar we notice, besides the augite and the magnetite, various spaces which are crowded with minute doubly refracting particles or with fibres which seem to extinguish parallel with their length. Some of the spaces have their whole area taken up by these minute fibres arranged in fan-shaped aggregates, and perhaps they represent minute vacuoles of irregular shape which have been infilled with chlorite. In other spaces we notice only scattered points or strokes of light in rotating under crossed Nicols, and there is a certain amount of a colourless glassy base present. There are also a few small amygdules of chlorite, or of chlorite and calcite, of a rude spherical form and often about ·025 inch in diameter. The felspar fibres near these show no indication of disturbance.

It is doubtful whether anything other than spherulites is shown in these three slices. The felspar does not always appear as fibres. There are parts where both it and the augite are in broader pieces without any clear order in their arrangement, and where the augite shows less numerous intersections by the felspar. These parts occur in thin stripes between the parts with the fibrous felspar, and have their greater lengths parallel to the average direction of the felspar fibres at their sides. Also, in part of slice 7947, in one of the spherulites which has been cut at a considerable angle to its radial lines, the felspar fibres appear much shorter than in the other spherulites of this and the other slices. Taking the appearances together, they are perhaps best explained on the supposition that the felspar is to some extent in the form of thin plates with their greatest lengths diverging from the centre to the edge of the spherulite, but with their broad sides *often* lying at considerable angles to one another. When the plates are cut nearly at right angles to their broad sides we get the thinnest fibres, but the lengths of the fibres vary according as the slice is cut parallel to the greater lengths of the plates or not. And in cases where the plates are cut nearly parallel to their broad sides the fibrous appearance of the felspar is lost.

The remaining sliced specimen (7846) was taken, as stated above, from a spot somewhat nearer the surface of the intrusion,

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and it shows features in some respects differing from those of the other examples. Glass is here richly present and is of a brown colour in the slice. The felspar fibres embedded in the glassy base are not so broad as before and become gradually more slender as they approach the surface of cooling. The magnetite specks decrease in size *pari passu* with the felspar. Olivine is present as abundantly as in the other slices, and of dimensions not much inferior; but here the crystals are of skeleton form, often with forked extremities, or they enclose relatively large glass-inclusions with a regular disposition (fig. 2). Augite is distinguishable in the part furthest away from this surface and occurs in the same way as in the other slices. Nearer to the surface the rock is very fine in grain and also more opaque, so that the different constituents, excepting the olivine and magnetite, cannot be satisfactorily separated. In this more opaque part there are, however, various clearer spaces, often from ·01 to ·003 inch diameter, which are occupied by growths of microlites in complicated arborescent forms. A few of these forms are seen within the spherulitic area and interrupt the fibres of it as if they were of earlier formation than them.

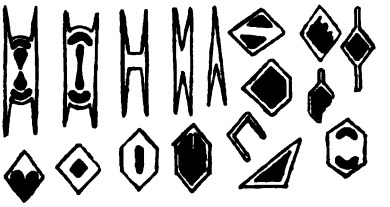

FIG. 2.

Another observation relates to the direction of elongation of the olivine crystallites. A large number, tested with a mica-plate, showed that the length of the section always coincides with the lesser axis of the ellipse of elasticity. Assuming then, what seems to be universally the case in olivine, that

$$a=\gamma, \qquad b=a, \qquad c=\beta,$$

it is clear that these crystallites are elongated parallel to the a–axis. This has been noticed before in olivine-crystallites, *e.g.* by Rinne[1] in the lavas of Vesuvius. In the Hawaiian basalts, on the other hand, Dana[2] found the crystallites to be greatly elongated in the direction of the c–axis. In slags, according to Vogt,[3] the common habit of olivine is tabular, the broad faces belonging to the pinacoid, b (010). In such minerals as the felspars and pyroxenes, as is well known, the general rule is that the crystallites are elongated parallel to the intersection of the principal cleavages: perhaps the greater variety

[1] Neu. Jahrb. für Min. 1891, vol. ii. pp. 272-280.
[2] *Amer. Jour. Sci.*, vol. xxxvii. p. 447, 1889.
[3] *Studier over Slagger*, p. 47, 1884.

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of habit exhibited by olivine may be connected with the absence of any very strongly pronounced cleavages. In the first three slides of our rock, described above, the olivine seems to have the forms and habit represented in fig. 3, A, without any very marked direction of elongation. In the slide now under notice we have the same forms, but with elongation parallel to the *a*–axis (fig. 3, B), or more usually with such imperfect development as is roughly shown in fig. 3, C. In some of the little cross-sections, however, it is seen that the form *b* is represented by only one of the pair of faces. This

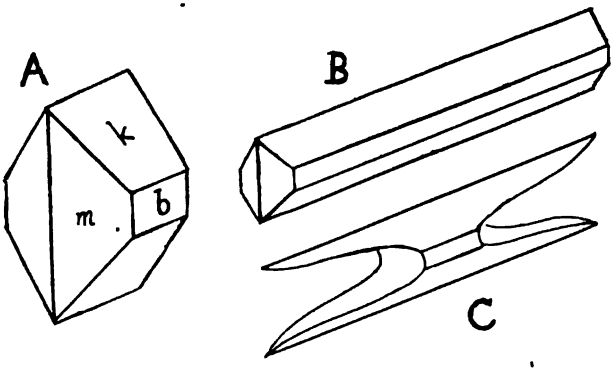

FIG. 3.

hemimorphism with respect to the b–axis has been remarked also by Rinne and others. The cross-shapes due to interpenetrating twins on (011) and (120), described by several writers, we have not observed in our rock.

Although no other rock has been found in Sleat showing structures comparable with those of the Camas Daraich occurrence on the same scale of magnitude, many of the trachytic or andesitic, and some of the basaltic, dykes of the district exhibit a variolitic tendency. The structure is usually on quite a small scale, and varies from mere fan-like and sheaf-like groupings of felspar fibres to complete radiate spherulites. It is often to be noticed, however, that the development of the structure as revealed in thin slices is much less perfect than might be inferred from the pronounced spherulitic appearance of exposed surfaces in the field.

FIGURES IN TEXT.

Fig. 1. Slice 7948, twice natural size (diagrammatic), showing portions of three spherulites with the polygonal boundaries due to their close packing. The lowest of the three is cut transversely to the direction of the fibres.

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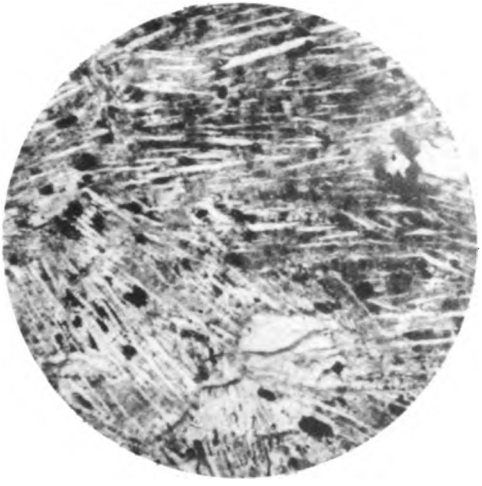

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Photo-Micro.—W. Forgan.

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Fig. 2. Skeleton-crystallites of olivine, × 100 to 150 ; slice 7846.
Fig. 3. Crystallographic habit of olivine ; A, in the general body of the rock ; B, in the more glassy variety ; C, in the skeleton-crystallites of the latter.

EXPLANATION OF PLATE XXIII.

FIG. 1, [7845] × 25, Natural Light. This illustrates the character of the general body of the rock. The figure includes only a small part of one of the large spherulites, its centre being well outside the field, so that the radiate arrangement of the slender felspar fibres which form so large an element in the rock is scarcely indicated. The olivine appears as small, clear crystals and crystal-grains, showing in places incipient conversion to serpentine at the margin of a crystal. The smaller opaque crystals are magnetite. The augite, which forms ophitic granules in the interstices of the felspar fibres, becomes conspicuous only when polarised light is used. A glassy residue is present here only in small amount, and is not apparent in the figure.

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LII.—*Contributions to the Petrology of the Cheviot Hills.* By Herbert Kynaston, B.A., F.G.S. (Plates XXIV and XXV.)

(Read 21st April 1890.)

1. Introduction.
2. The Cheviot Granite.
3. The Dykes and Sills.
4. The Relations between the Granite, the Dykes and the Andesites.

1. *Introduction.*—It has now been known for some time that the Cheviot district constitutes a fairly extensive area of andesitic lava-flows of Lower Old Red Sandstone age, surrounding an inner mass of augite-granite, while both are traversed by a large number of associated dykes and sills. But until the English side of the Cheviots was mapped for the Geological Survey by Mr C. T. Clough, not very much detailed petrographical work had been done amongst the igneous rocks of this area by earlier observers. Before, however, the Survey Memoir was completed, Mr J. J. H. Teall had visited the district, and published the results of his observations in a series of papers in the *Geological Magazine*.[1] The principal varieties of the contemporaneous lavas are therein fully described, and some of the more characteristic types of the granite; but only one type of the more acid intrusives is noticed in any detail.

In the course of several visits to the Cheviots, I devoted special attention to the intrusive rocks of the district, and their relation to the andesitic lava-flows. And it is the object of the present paper to describe certain features exhibited by the former, which do not yet appear to have been previously noticed in this district, and to point out the relationships between the various types of igneous rock that are here met with.

I would take this opportunity of acknowledging my indebtedness to the detailed and careful mapping and descriptions of Mr C. T. Clough, while examining the rocks in the field. I would also thank Messrs A. Harker and J. J. H. Teall for valuable hints and suggestions.

2. *The Cheviot Granite.*—The Cheviot Granite, which occupies the central and more elevated portion of the district, was first

[1] *Geol. Mag.*, Dec. 2, vol. x. (1883), pp. 100, 145, 252, 344; *Geol. Mag.*, Dec. 3, vol. ii. (1885), pp. 106-121.

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GEOLOGICAL MAP OF THE CHEVIOT DISTRICT (English Side)

From the published Map of the Geological Survey (Scale, 4 miles to 1 inch).

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examined by modern petrological methods and described, by Mr. J. J. H. Teall,[1] and it was shown by him that the normal type was an augite-biotite-granite, possessing strong affinities to the augite-bearing granitites of Laveline and Oberbrück in the Vosges, described by Rosenbusch and Cohen. The augite was shown to be a non-aluminous iron-bearing species of the diopside type (malacolite of Rosenbusch), allied to that of the augite-syenite of Monzoni. A considerable amount of variation is exhibited in the mass, both in texture, structure, and the relative proportion of the different constituents.

The normal or most common type is a pale pink or greyish granite of fairly coarse grain and usually non-porphyritic, containing a soda-orthoclase as the dominating felspar. Sometimes, however, the rock becomes finer-grained, and, owing apparently to an increase in the relative proportion of the ferro-magnesian constituents, assumes a dark, syenitic or dioritic aspect. This variety is especially well exposed towards the margin of the main mass, in the neighbourhood of Linhope, and in the river Breamish above Linhope. On the other hand, fine-grained varieties often occur, also towards the marginal portions of the mass, of a pinkish or flesh-coloured tint, in which the ferro-magnesian element plays but an insignificant part. And between these two extremes every gradation may be found, showing a gradual passage from the one to the other. The dark varieties near Linhope appear to have strong affinities with the rocks of Markfield and Groby in Charnwood Forest; hornblende, however, is not known to occur as an original constituent in any Cheviot rock. The more acid fine-grained varieties may be compared with the well-known augite-bearing granophyres of Charnwood Forest, Carrock Fell, Craig-Craggen in Mull, and those of the Carlingford district and the Mourne Mountains in Ireland, etc. In the Cheviot district, then, we may say that the more coarse-grained type occupies, as a rule, the more central part of the granite area, about Staindrop Rig, Hedgehope, Cheviot, and Comb Fell, while the finer-grained varieties, whether more, or less, acid than the normal type, occur mainly towards the margin of the mass.

Some of these finer-grained varieties are occasionally porphyritic, though this feature is not conspicuous or by any means common.

The microscopic examination of a large series of slides prepared from rocks collected in different parts of the granite area entirely confirms the observations already made by Mr Teall, and also brings out several additional points of interest.

The occurrence of augite is always extremely characteristic.

[1] *Ibid.*, 1885, pp. 106-121.

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When fresh, it is practically colourless, but often has a greyish dusty appearance, owing to minute inclusions, or, when altered, it may be converted into a pale green slightly pleochroic fibrous amphibole [29] [33] [35] [44]. Further decomposition results in the production of pseudomorphs of chlorite or calcite. Mr Teall noticed in one case what was most probably a rhombic pyroxene,[1] and this observation I can fully confirm, as I find a pale enstatite, very similar to that so characteristic of the andesites, to be of by no means uncommon occurrence in some of the granites, especially those of Staindrop Rig, Linhope and Dunmoor Hill [27] [33] [35] [47a]. As a rule, it does not show any definite crystal form, but occurs, generally in association with the augite phenocrysts, as more or less irregular patches. It can be distinguished from the augite by its characteristic, though faint, pleochroism, and by its tendency in the less fresh examples to be replaced by bastite-like pseudomorphs.

The biotite generally occurs as rather ragged plates, frequently in association with the pyroxene. It often has the appearance of having been subjected to a certain amount of magmatic corrosion, having a ragged edge, which is often partially surrounded by small granules of magnetite and pyroxene [29] [33] [34]. Acccording to Rosenbusch,[2] such corrosion is by no means uncommon in porphyritic rocks, in which, "if the older biotite has been subjected to magmatic corrosion, it is surrounded, like basaltic hornblende, with a dark border, which consists of a mixture of magnetite and augite." Under the action of decomposing agencies the biotite loses its characteristic colour and becomes greenish and chloritised [31] [44], etc.

The quartz and orthoclase nearly always show a marked tendency to form the characteristic intergrowth known as micropegmatite, which plays the rôle of groundmass. In the normal type of granite this micropegmatite is of a relatively coarse and ill-defined character, but in the finer-grained varieties it nearly always shows the fine delicate structure so characteristic of the typical granophyres. In fact the ordinary and coarser type of granite from the more central portion of the area can frequently be traced into granophyres towards the margin of the mass, while similar granophyric types are found in numerous dykes and veins.

The constituent minerals of these granophyres are the same, in slightly varying proportions, as these of the normal granite,

N.B.—The numbers in square brackets throughout this paper indicate slides in the author's collection.

[1] *Geol. Mag.*, 1885, p. 115.

[2] Rosenbusch and Iddings. Microscop. Physiog. of Rock-forming Minerals, p. 260.

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while they usually have a decidedly porphyritic aspect owing to the much finer texture of the later-formed portion. They vary from a pink to a greyish colour. The microscope shows that this difference is due to the fact that the darker varieties contain a larger proportion of pyroxene and biotite [61], while the pink or flesh-coloured granophyres show more felspar and quartz. There is no sharp line of demarcation, however, between the two. A slide from one of the more acid varieties from the river Breamish shows [31] much porphyritic plagioclase and biotite, of which the latter, however, has been almost entirely converted into chloritic alteration products. Only a very little augite is present, and that much decomposed. The ground mass of the rock consists of a delicate and finely intergrown micropegmatite, which is often associated with the porphyritic felspars in the characteristic manner so frequently observed in granophyric rocks.

A fairly similar well-marked micrographic variety of the normal granite occurs in the burn about half mile west of Dunmoor Hill. Under the microscope [70] porphyritic orthoclase is seen to be present in almost the same quantity as the plagioclase. Augite is very scarce, and much decomposed. The biotite is chloritised from alteration, and occurs in fair-sized plates. The greater proportion of the rock consists of a micropegmatite of medium texture, playing the rôle of ground mass. As an accessory tourmaline is also observed in irregular grains and crystal groups, and longitudinal sections show the characteristic pleochroism, pale brown passing through bluish-brown to a deep indigo.

Towards the northern portion of the granite area, near the head of Bazzle Burn, and on the N.E. side of Cheviot, granophyres are again well exposed. A hand specimen is of a pink colour and moderately fine-grained in appearance, and shows prominent hexagonal plates of biotite, often of a greenish colour from decomposition. Under the microscope [60] a slide shows a few fair-sized phenocrysts of plagioclase, and long, thin, lath-shaped sections of biotite, sometimes over $\frac{1}{8}$ inch in length, embedded in a fine-grained ground mass, consisting of small idiomorphic plagioclase crystals, flakes of biotite, quartz grains, and micropegmatite. Pyroxene is apparently only represented by one or two small patches of greenish decomposition products. Tourmaline occurs here also in irregular crystalline grains scattered throughout the rock. It varies in colour from brown to bluish brown and dull bluish green, and shows the characteristic resorption phenomena. Tourmaline is also found in the Cheviot granites in considerable quantity in certain areas where a good deal of faulting has taken place, especially near the

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headwaters of Lambden and Hawsen Burns, and here a curious quartz-tourmaline vein-rock is very common, in which the tourmaline usually occurs as acicular microlites, often aggregated into radiating groups, in the manner so characteristic in Luxullianite. In such rocks, as well as in the tourmaline-bearing granophyres, this mineral would seem to be of secondary origin, and the fact of its occurring in greater quantity in the neighbourhood of faults would seem certainly to support the idea of its origin being connected, as is supposed to be the case in some of the Cornish granites, with exhalations of boracic and fluoric acids. In the Cheviot district, with the exception of the areas of faulting referred to, the occurrence of tourmaline seems to be limited to the more marginal portions of the granite mass, and this is also the case in the tourmaline-bearing granites of Cornwall and Devon.

Such are the principal varieties of rock which compose the central granitic mass of this district. As regards the chemical composition of the Cheviot granite, Mr Ivison Macadam, F.R.S. of Edinburgh, has kindly analysed for me specimens of two different varieties, viz., the normal type from Staindrop Rig, and the dark, finer-grained variety from near Linhope, and the results of these analyses are here given:—

	I.	II.
SiO_2	66·02	67·12
Al_2O_3	21·43	20·12
Fe_2O_3	4·62	3·71
FeO	0·63	0·28
CaO	1·81	1·79
MgO	1·77	0·82
K_2O	3·17	3·38
Na_2O	0·15	1·53
SO_3	0·04	0·05
CO_2	0·08	0·03
H_2O	0·16	1·01
	99·88	99·84
	Sp. Gr. 2·731	Sp. Gr. 2·701

I. Fine-grained dark grey granite, Black Lynn, Linhope.
II. Fairly coarse granite, Staindrop Rig.

One sees that there is not so much difference between these two varieties, as one would at first be led to expect from their appearance. One would have perhaps expected rather a lower silica percentage in the dark, dioritic-looking type, which I think may fairly represent the least acid type in the district.

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Some of the granophyres, noticed above, are doubtless a good deal more acid than the Staindrop Rig rock, as they contain far more quartz and orthoclase, and in many cases only a very small amount of augite and biotite, so that they would probably show at least 70 per cent. of silica. There does not, therefore, seem to be any very considerable amount of variation in chemical composition throughout the mass of the Cheviot granite, certainly not nearly so much as in many cases described, such, for instance, as is found in the granitic mass of Garabal Hill and Meall Breac, described by Dakyns and Teall.[1]

It may not be out of place before leaving the granite to refer briefly to certain supposed cases of a gradual passage between the augite-granite and the surrounding andesites. Mr Clough in the Survey Memoir on the English side of the Cheviot district says[2]: "In certain places near the margin of the area . . . . the rock (*i.e.* the granite) is dark grey or brown in colour, and so finely crystallised that it is hard with the eye to separate it from the darker porphyrites. Indeed, one could not help suspecting that they occasionally passed into one another." But if we are to regard the granite as intrusive in the surrounding andesites, and the presence in these latter of undoubted contact metamorphism, and other phenomena, prove distinctly that this is the case, then it is certainly difficult to see how any gradual passage between the two rocks can possibly exist.

In one locality, viz., in Broadstruther's Burn, a short way above its junction with Common Burn, the granite certainly does appear at first sight to pass gradually into the andesite, as one follows the section exposed down the burn. The granite, which is here porphyritic, gradually becomes dark in colour and fine grained, as one approaches the andesite, which is also of a dark grey colour, and assumes a somewhat holocrystalline appearance in the neighbourhood of the granite. The exposure has decidedly the appearance of a gradual passage to the naked eye, and no definite line of junction between the two rocks can be detected. However, on examining under the microscope a series of slides [23], [24], [25], [26a], [26b], the distinctive characters of the granitic rock on the one hand, and the andesitic on the other, are at once apparent. And, what is more, the andesites show undoubted signs of contact alteration, which would at once negative any idea of a true original passage between them and the granite. It is the general resemblance in the colour and texture of the two rocks which gives the appearance of a gradual transition from the one to the other. It is perhaps possible that we have here a kind

[1] *Quart. Journ. Geol. Soc.*, 1892, p. 104.
[2] Mem. Geol. Survey (Sh. 108 NE.), p. 21.

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of blending together of the two rocks at the contact, due to the margin of the andesite having been fused as the granitic magma was intruded into it, though there is hardly the degree of alteration in the andesites that one would have expected if such a refusion had taken place.

On the whole, my own observations, both in the field and with the microscope, lead to the conclusion that all so-called passages in this district between the granites and the andesites are in reality only apparent, and constitute contacts between an intrusive rock, on the one hand, and a contemporaneous rock, on the other hand, of an extremely intimate character.

We may now briefly sum up the chief points that are brought out by a study of the Cheviot granites. Firstly, we may notice the recognition of an enstatite-bearing variety, in the neighbourhood of Linhope, Staindrop Rig, and Dunmoor Hill. The occurrence of enstatite in granitic and granophyric rocks containing quartz and orthoclase has been occasionally noticed by previous observers, but it is by no means a common feature. According to Sir Archibald Geikie,[1] a rock fairly similar to the normal Cheviot granite has been noticed by Professor James Geikie, associated with the Lower Old Red Sandstone volcanic rocks of the east of Ayrshire. And another variety, mapped by Mr B. N. Peach, occurs in the Ochil Hills, above Tillicoultry. "It is a granophyric quartz-diorite, which under the microscope is seen to be composed of short, thick-set prisms of plagioclase, with abundant granophyric quartz, a pleochroic hypersthene, and needles of apatite."

Then we have the enstatite-diorite of Penmaenmawr, and the coarser varieties of the whin sill of Upper Teesdale, which frequently consist of a coarse enstatite-dolerite, in which micropegmatite plays the rôle of groundmass. Mr Alfred Harker tells me that enstatite-bearing granites occur in Norway and Southern India; and one might also mention in this connection certain augite-bearing quartz-porphyries, which contain a rhombic pyroxene,[2] in North Saxony, near Leipzig.

As regards the felspar of the Cheviot granite, we sometimes find plagioclase predominating over orthoclase, while sometimes again it is subordinate; occasionally both may be present in about equal proportions. The strong tendency to the granophyric structure has already been referred to, and recalls the well-known granophyres of Craig Craggen in Mull, Charnwood Forest, the Carlingford district and the Mourne Mountains in Ireland, and the augite-bearing granophyre of Carrock Fell, so

[1] *Q. J. G. S.*, vol. xlviii. p. 77 (Anniv. Address of Pres.). "Ancient Volcanoes of Great Britain," vol. i. p. 277.

[2] Rosenbusch, Massige Gesteine, p. 58.

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ably described by Mr Harker.[1] In the Cheviot district the granophyric types are especially noticeable towards the marginal portions of the main mass. Distinctly porphyritic varieties, in which plagioclase is the dominating phenocryst, are occasionally met with [28], etc.

I have not come across any undoubted case of hornblende occurring as an original constituent of any Cheviot granite, though a slide from a granite boulder from this district in the Survey Collection in Jermyn Street shows small brown crystals of idiomorphic hornblende [1391]. The occurrence of tourmaline, however, near the margin of the main mass and in small veins, is extremely characteristic. Its presence, too, in considerable quantity, in the neighbourhood of faults, might possibly throw some light on its mode of origin.

Lastly, the presence of considerable variation in the relative proportion of the different constituents must not be overlooked. This variation would appear, in this district, to be a marginal modification, resulting sometimes, as seen near Linhope, in a rather less acid variety than the normal type, and sometimes, on the other hand, as in the North and North-West of Cheviot, in the more acid and finer-grained granophyres. So that the differentiation, though essentially of a marginal type, is by no means uniform from the centre to the margin of the main mass of the granite, as, for instance, has been shown to be the case with the Gabbro of Carrock Fell.[2] The type of magmatic differentiation, however, which is illustrated in this district, I shall discuss more fully in connection with the relations between the granite, the dykes, and the contemporaneous lavas.

3. *The Dykes and Sills.*—Among the numerous dykes and sills which are found intersecting the Cheviot granite and the surrounding lavas, one may recognise two fairly distinct types: (1) an intermediate, and (2) an acid type. The mode of occurrence of most of these dykes and sills in the field has been well described by Mr Clough,[3] and the microscopic characters of some of them have been described by Mr Teall[4] and Mr Watts.[5] A considerable number, however, have as yet remained unnoticed by any petrologist, many of which show various additional characteristics to those already recorded, and which are well worth noticing. I propose, therefore, to describe the microscopical characters of some of the more interesting dykes and sills that I have examined in the field, and shall also endeavour to show that, in examining a series of thin sections

[1] *Q. J. G. S.*, 1895, p. 125 *et sqq.* [2] *Q. J. G. S.*, 1894, p. 311.
[3] Mem. Geol. Survey. The Cheviot Hills, pp. 26-29.
[4] Teall, *Geol. Mag.*, vol. x. pp. 255-257. Brit. Petrog., p. 281.
[5] Mem. Geol. Survey (¼ sheet 110 SW.), Geology of part of Northumberland, p. 62.

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prepared from dyke-rocks occurring in different parts of the district, one will come across varieties which constitute connecting links, or transitional types, between the intermediate and the acid type. We will first of all consider the intermediate series.

(1) *The Intermediate Type.*—These consist mainly of *Mica Porphyrites.* Before describing them, however, it will be as well to explain, as nearly as possible, the exact sense in which the term "Porphyrite" is here used. If we employ the term "Porphyrite," as it has been so frequently used in petrographical literature, to signify a more or less altered (decomposed) rock, showing in other respects the characters and structure of an andesite, we cannot draw any petrological distinction between the dyke-modification of the andesitic magma and the corresponding lavas. I propose then in what follows to employ the term "Porphyrite" in the same sense in which it is used by Mr J. J. H. Teall in describing some of the dykes associated with the Criffel and Dalbeattie granites,[1] that is to say, as referring to a porphyritic rock, usually constituting dykes and sills, in which plagioclase is the predominating felspar, and which may be said to bear "the same relation to the andesites that the porphyries do to the liparites." The only difference between the Cheviot porphyrites and those above referred to, as described by Mr Teall, is that the former belong rather to the class of pyroxene-porphyrites, while the latter would be classed as hornblende-porphyrites.

We find, then, that in the area under consideration the dykes and sills constituting the intermediate type are composed of porphyritic rocks with a groundmass more or less compact to the unaided eye. The rocks vary in colour from a dark grey, when fairly fresh, through various shades of purple to a brick-red, when decomposed. The phenocrysts consist of plagioclase, biotite, and augite; enstatite, of a similar type to that of the enstatite-andesites has occasionally been noted, as well as small grains of quartz. Orthoclase is sometimes present, but is always subordinate to plagioclase. A considerable variation is noticeable in the relative proportion of the phenocrysts to the ground mass, and this I believe is a common character in all rocks of this class.

To take a few examples. At a bend in the Carey Burn, near Wooler, and a short way below the junction of the Common and Broadstruther's burns, a purplish porphyrite occurs as a fairly large intrusive mass. It may possibly represent a neck, or perhaps an intrusion of the laccolitic type. Under the microscope [16], one sees fairly numerous crystals of plagioclase, (probably oligoclase), and plates of biotite. The biotite is fairly

[1] Mem. Geol. Survey, Scotland, sheet 5 (1896), p. 44.

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fresh, though commencing alteration is frequently shown at the edges of the phenocrysts and running in along the cleavage cracks. Pyroxene, in crystalline grains, was evidently present in the fresh rock, though in no great quantity, but it is now only represented by chloritic and calcareous alteration products. A few small grains of quartz are also present. The ground mass consists of a microcrystalline aggregate of small crystals of plagioclase, flakes of chloritised biotite, orthoclase and quartz. Magnetite and apatite are both fairly abundant as accessories, and both are common as inclusions in the phenocrysts.

In the Common Burn, especially in the neighbourhood of Common Burn House, several dykes of porphyrite are exposed. Their groundmass varies in structure almost from a confusedly cryptocrystalline [64] to the microgranitic [66]. Small quartz grains resembling those of the quartz-porphyries are sometimes present, and are generally corroded.

The plagioclase phenocrysts are much decomposed and show micaceous alteration products. The biotite is generally entirely converted into chlorite, and a fair amount of pyroxene is present. A few greenish and fibrous pseudomorphs [66] appear to represent enstatite. Sometimes the augite appears fresh and almost colourless, and shows well-defined crystal outline [27], and bastite-like pseudomorphs after enstatite are clearly recognisable [27].

In the valley of the Breamish an intrusive biotite-porphyrite is well exposed just below Linhope House. Augite, in a uralitised condition, is fairly plentiful [67], [68]. Grains of quartz occur, occasionally intergrown with orthoclase so as to form a porphyritic aggregate of micropegmatite [68]. In the ground mass again we find a very fine delicate type of micropegmatite, representing the final phase of crystallisation from the mother-liquor. We thus get two phases during which micropegmatite was formed. Besides the phenocrysts of intergrown quartz and orthoclase simple porphyritic crystals of both minerals also occur. Another rock, which occurs as a dyke in the granite on the S. side of Dunmoor Hill, near Linhope, shows this feature rather better. The rock contains [15a, 15b, 46] phenocrysts of plagioclase, biotite, augite, and occasionally enstatite may also be observed. Towards the margin of the dyke numerous phenocrysts of micropegmatite occur. In many points these structures closely resemble the granophyre groups described by Iddings[1] from the rhyolitic rocks of Obsidian Cliff, and Eureka, Nevada. In the Cheviot slides, however, especially in some of the quartz-felsites to be described, they are considerably larger and show a coarser intergrowth of the two minerals. In the rhyolite from Eureka quartz has been intergrown with

[1] Seventh Annual Report (1886) U.S. Geol. Survey, p. 275.

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felspar, and is also enclosed within it, so that the felspar crystals retain their characteristic outline. Hence the form of the phenocryst is determined by the felspar, and shows that it continued to crystallise out after the quartz had ceased. Mr Cowper Reed [1] describes similar granophyre groups in felsitic lavas from Goodwick, near Fishguard, and Mr Reed was good enough to allow me to compare his slides with my Cheviot examples. In the Goodwick rocks the outline of the granophyre groups is more usually determined by the quartz, not by the felspar, so that the marginal portion consists of a series of wedge-like protrusions of quartz, which more or less completely encloses the felspar. The outline in section of such a group will correspond to that of one, or more commonly a group of, quartz crystals.

In all the examples that I have seen from the Cheviots, however, the form of the group is usually determined equally by both minerals, so that the outline is that of a porphyritic aggregate of felspar and quartz, each mineral being idiomorphic along the outer margin of the group.

We thus have a porphyritic individual or phenocryst consisting of a micrographic intergrowth of quartz and orthoclase, the external contour of which may be determined by either the quartz or the felspar, according to whichever continued to crystallise out after the other, or it may be determined by both minerals equally, in which case both probably ceased to crystallise out about the same time.

Plagioclase occasionally occurs in association with these groups, but it does not appear to be intergrown with the quartz. Possibly, as in the example described by Iddings from Eureka, Nevada, the quartz and orthoclase crystallised out about the plagioclase as a kind of nucleus.

There is no doubt that these groups constitute distinct porphyritic elements and are indigenous to the rock in which they occur. They are always sharply and distinctly separated off from the ground mass, and are generally bounded by crystal outlines, as I have already pointed out; so that there is no possibility of confusing them with the micropegmatite, which constitutes such a well-known feature of the groundmass of many granitic rocks. They belong undoubtedly to the earlier or plutonic phase of consolidation of the magma, the conditions of which were suddenly interrupted on the injection of a portion of this magma into a fissure to form a dyke. If this consolidation could have been continued unchecked, in all probability a rock would have been formed closely resembling the normal finer-grained granites of the district, in which a free intercrystallisation of quartz and felspar is a common feature.

[1] *Q. J. G. S.*, vol. li. (1895), p. 162, pl. vi., figs. 3, 4, and 5.

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Micrographic structures, essentially similar to the above, have been described and figured by Professor Judd [1] from the Isle of Skye. He regarded them, however, as representing remnants of derived fragments of granophyre, which had been caught up by the Gabbro and refused, the "granophyre groups" being those portions which had escaped refusion. It was, however, conclusively shown by Sir Arch. Geikie [2] that the rock in which these structures occur is to be regarded as constituting small dykes and veins of spherulitic felsite traversing the Gabbro, and not as partially refused fragments. It is interesting to find, therefore, that the petrological evidence of these granophyre groups strongly confirms Sir Archibald's conclusions. They occur in a felsitic rock possessing the type of ground mass commonly known as the "pseudospherulitic," and they are usually found in the nuclei of the pseudospherulites, or in other words, the matrix behaves with respect to these groups in exactly the same characteristic manner as this type of ground mass behaves with regard to phenocrysts of felspar and quartz in so many felsitic and granophyric rocks. They constitute in fact normal porphyritic groups in a felsitic rock of by no means uncommon type. And from the comparative frequency with which these structures occur in the dyke rocks of the Cheviot district and of other areas, and from other facts already noticed, we may infer that they are decidedly original and unaltered structures characteristic of the quartz-felsites and allied rocks, more especially of the granophyric varieties.

The rock from Dunmoor Hill, in which these granophyre groups occur, was analysed for me by Mr Ivison Macadam, F.R.S.E., etc., with the following result:—

SiO_2 . . .	60·84
Al_2O_3 . . .	20·03
Fe_2O_3 . . .	1·47
FeO . . .	0·42
CaO . . .	1·56
MgO . . .	0·45
K_2O . . .	4·43
Na_2O . . .	9·12
SO_3 . . .	0·06
H_2O . . .	1·15
CO_2 . . .	0·11
	99·64
Sp. Gr. . .	2·683

[1] *Q. J. G. S.*, vol. xlix. (1893), p. 189.

[2] *Q. J. G. S.*, vol. l. (1894), p. 212.

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The extraordinary high percentage of the soda makes it difficult to doubt that this is not largely overestimated. With this exception the analysis resembles on the whole those of the augite-andesites of the same district described by Teall,[1] the alumina percentage being perhaps in our dyke-rock rather higher.

I have now described the main petrological features of the dyke-rocks of the intermediate or porphyrite type. The occurrence of enstatite in some of these rocks is worthy of note, and serves to show the relations between them and the augite-granites on the one hand, and the andesitic lavas on the other. Another mineral of interest, which I have also noticed in several specimens of the andesites, is a bluish and violet apatite, doubtless similar to that described recently in the Transactions of this Society, by Dr Flett, in an andesite from the Ochils.[2] This is well shown in the Dunmoor Hill dyke, occurring in short stumpy prisms, and showing a distinct pleochroism.

The variation in the relative proportion of the different constituents is well marked in these rocks. Thus while biotite, among the ferromagnesian constituents largely predominates throughout, the proportion of augite and felspar varies considerably. Some may be classed as fairly typical augite-bearing biotite-porphyrites. In others again we find the proportion of ferromagnesian minerals, especially the augite, becoming smaller, while quartz and orthoclase make their appearance among the porphyritic; and these latter, as we have seen, may occasionally be intergrown, to form the granophyre groups. These latter varieties would appear to constitute connecting links between the porphyrites and the quartz-porphyries. The groundmass is usually of the microcrystalline type, consisting mainly of quartz and felspar. This will pass into the cryptocrystalline, or at times it will approach the micropoikilitic [15], while in others again the groundmass might be described by Mr Harker's term 'cryptographic,'[3] an extremely minute micropegmatitic growth appearing to fill up the interspaces between the last formed minerals [11], [19], [92].

Acid Type.—This type of dyke-rock in the Cheviot district comprises two fairly well-marked species, which, however, are closely related through intermediate varieties.

Almost all the rocks belong to the quartz-felsites, but for the sake of convenience we may divide them into (*a*) those without micropegmatite, corresponding to the felsophyres of Vogelsang,

[1] *Geol. Mag.*, 1883, p. 107, and 1885, p. 118.
[2] Trans. Geol. Soc., Edin., vol. vii. p. 292.
[3] See Q.J.G.S., vol. li., 1895, p. 129.

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and (*b*) those with micropegmatite, corresponding to the granophyres of Rosenbusch. We will notice those of the felsophyre class first. In the Alwinton district a well-defined dyke occurs in the Usway Burn nearly a mile above its junction with the Coquet. From this point it runs nearly due south-west and is exposed in the Coquet a quarter of a mile above Shillmoor, and again in the Ridlees Burn, east of Quickening Coat. This rock has been well described by Mr Teall.[1] I will here, however, briefly notice some of its more important characters, as I consider that it shows relationships to some of the more acid varieties of the quartz-bearing biotite-porphyrites, such as the dyke from near Linhope House [68], already described above. Under the microscope [55], [56], [57], [58] biotite is at once seen to be the most important mineral. It occurs in numerous small hexagonal tablets and elongated rectangular flakes. Quartz is fairly plentiful and generally occurs as irregular corroded crystalline grains, but occasionally shows crystalline outline. The felspar consists of two varieties, lath-shaped individuals, which are of the same colour as the groundmass from alteration, and which can be recognised as plagioclase, and clear individuals of a tabular habit, but often more or less corroded, and showing Carlsbad twinning. These latter appear to be sanidine, and are well shown in the rock from Ridlees Burn [57]. The ground mass varies from micro- to crypto-crystalline. Another dyke of the same character occurs in the Lambden Burn, near Goldscleugh. These rocks may be termed biotite-quartz-felsites, and resemble in many respects the mica-bearing quartz-porphyries described by Messrs Marr and Harker from the Shap district.[2] The same authors also mention sanidine as occurring in some of the dykes of that district.

At Low Bleakhope we find another rock which forms a connecting link between the porphyrites and the quartz-felsites, and it is difficult to say to which class it should be assigned. Under the microscope irregularly shaped and much corroded quartz grains are seen of the usual quartz-felsite type. Both plagioclase and orthoclase occur; biotite and chloritic pseudomorphs after pyroxene are present in a proportion almost equal to that of the quartz [101], [102], [103]. The ground mass is microcrystalline and resembles that of many of the mica-porphyrites, and consists of small lath-shaped plagioclases, orthoclase, quartz, magnetite granules, and chlorite alteration products. The margin of the dyke has a slightly fresher appearance and shows excellent fluxion structure.

The remaining dyke-rocks which I have classed with the

[1] *Geol. Mag.*, Dec. 3, vol. ii. (1885), p. 107. British Petrography, p. 343.
[2] Q.J.G.S., vol. xlvii. p. 285.

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felsophyre type do not call for any special description. They are mostly normal quartz-porphyries of the type so common in granitic regions. As a rule both orthoclase and plagioclase are present, the former being frequently the dominant felspar. Occasionally, when a comparatively small amount of quartz is present, and orthoclase is in excess of the plagioclase, we may get an orthoclase-porphyry or orthophyre, such as has been described by Mr Watts, from the northern portion of the Cheviot area.[1] The proportion of biotite, too, varies considerably in the different slides I have examined [53], [54], [100].

There cannot be said to be any sharp line of difference between the felsophyre type and the granophyric. A distinction based merely on difference of texture in the groundmass of unaltered rocks can only depend upon slightly varying conditions of consolidation. For we may occasionally find the two types of groundmass, the micrographic and the microcrystalline, together in the same slide [50], or again the central portion of a dyke may show the micrographic, while the margin will show the microcrystalline [97], [98], [99]. It will be sufficient therefore to notice the more interesting points in connection with the remaining dyke-rocks, which I have placed provisionally in the granophyre class. Plagioclase generally occurs in addition to orthoclase, but is usually subordinate to it, though in one or two slides the porphyritic felspars are mainly plagioclase [89], [20]. Biotite is usually present, occasionally in very elongated strips and flakes. Sometimes it is almost entirely absent [62], [90]. In decomposed specimens it is wholly or partially replaced by chloritic alteration products. Pyroxene is rare, but occasionally makes its appearance, sometimes as phenocrysts, generally showing more or less alteration [20], [89], or as small grains in the groundmass [95], [70]. A few small grains of brown tourmaline now and then occur as an accessory [100], [95], [70].

But the most interesting feature of these rocks is the frequent occurrence of the granophyre groups, which have already been noticed above as occurring in one of the porphyrites. But in the rocks under consideration we not only have micrographic quartz and felspar constituting phenocrysts of the earlier phase of consolidation in the form of granophyre groups, but we again have an extensive development of micropegmatite of varying texture constituting the later phase of consolidation of the magma in the ground mass. Two or three dykes showing this feature occur about ½ mile below Low Bleakhope on the

[1] Mem. Geol. Survey. [Sheet 110 SW.] Geology of part of Northumberland. Petrological Notes by W. W. Watts, p. 62.

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river Breamish. Porphyritic quartz is seen to occur independently, besides taking part in the formation of the porphyritic micropegmatite [51], [62]. Sometimes a section of one of these groups has the appearance of one or more felspar crystals, containing a number of separate, more or less triangular-shaped, inclusions of quartz, which are in optical continuity, or sometimes the inclusions of quartz may extinguish in separate groups, when rotated between crossed nicols. Or again a section may show irregular strips and patches of felspar included in the quartz. The intergrowth constitutes a rather coarse irregular type of micropegmatite, and can be frequently seen to be associated with a crystal of plagioclase. It forms genuine porphyritic groups sharply marked off from the surrounding groundmass. And this ground mass again is of the finely micrographic type, and constitutes a delicate feathery or plumose variety of micropegmatite, of a much finer type than that forming the groups, and fills up the interspaces between the last formed crystals. Biotite is rather scarce in these rocks, and there seems to be no sign of any pyroxene, and only very little magnetite.

Evidently we have here a group of distinctly acid rocks consisting for the most part of orthoclase and quartz, and in which micropegmatite has been formed at two distinct periods. We have been accustomed to regard micropegmatite as representing the very final phase of consolidation of a magma; but we have very clear evidence in these rocks that micropegmatite can belong, not only to the final phase, but also to a comparatively early phase of consolidation. Thus after magnetite, biotite was the first mineral to crystallise out of the magma, and it was followed presumably by plagioclase. Then apparently orthoclase and quartz crystallised out at the same time, either to form independent idiomorphic crystals, or to form an intergrowth in association with the already formed phenocrysts of plagioclase, thus constituting the granophyre groups. At this stage, however, crystallisation under plutonic or intratelluric conditions suddenly ceased, a portion of the magma was forced into a fissure, and under these new conditions of consolidation occurred the second formation of micropegmatite to constitute the groundmass of the dyke, and this was naturally of a variety far finer in texture than that already formed, owing to the greater rapidity in cooling which ensued during the fissure-phase.

As to the exact conditions necessary for the formation of micropegmatite, we cannot in the present state of our knowledge make any definite statement. If we are to regard micropegmatite as an eutectic compound, it seems evident that such

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a compound can be formed by quartz and felspar only under certain conditions of which we are ignorant. Otherwise we should expect to find micropegmatite in the ground mass of any rock in which the mother liquor had the chemical composition of quartz and orthoclase, and we know that this is not the case from the frequent occurrence in granitic rocks of insterstitial quartz and felspar, in which the crystallisation of either mineral may *precede* the other. If, however, a eutectic compound is invariably formed in such a mother liquor, it is evident that it cannot always give rise to the micrographic structure without the concurrence of particular physical conditions. In many cases in the so-called microgranitic groundmass there may be a certain amount of simultaneous crystallisation without the occurrence of typical micropegmatite or its allied structures.

It is very clear that in the rocks under consideration the physical conditions of consolidation strongly favoured the formation of the granophyric structure, and from the frequent occurrence of the granophyre groups in the porphyritic rocks we may further conclude that these conditions were present during both phases of consolidation.

The micropegmatite of the second generation (or second period of consolidation) may be aptly compared with that described by Mr Harker in his paper on the Granophyre of Carrock Fell.[1] The granophyric structure in this rock, to use the author's own words, "exhibits various stages of gradation from a coarse and irregular micropegmatite to spherulitic intergrowths of a delicacy surpassing the resolving power of the microscope." In the Cheviot rocks, however, I have not noticed any marked tendency to the centric or radiate arrangements. One may observe, however, almost every gradation between a fairly coarse and ill-defined intergrowth to what might be called 'cryptopegmatite,' or, to use Mr Harker's term, the 'cryptographic' structure [62], [100].

Small veins and bands of more acid material are very numerous in the Cheviot granite, and are especially well seen in Linhope Burn and in the river Breamish. At Linhope Spout, for instance, two or three small bands, less than a foot in breadth, traverse the granite just at the top of the waterfall. Mr Clough, in connection with these and other similar exposures, says[2]:—"In some cases they may be contemporaneous veins rather than intrusions, and Mr Teall is inclined to hold this view in respect to the quartz-felsite bands at Linhope Spout. On the other hand, the sides of some of them are distinctly finer-grained than the interiors, as if they had been chilled by

[1] Q.J.G.S., vol. li. (1895), p. 127.
[2] Mem. Geol. Survey (The Cheviot Hills), p. 22.

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intrusion into an already consolidated cooler rock-mass. . . . We know also that there are undoubted dykes of much the same character among the contemporaneous rocks." My own observations have led me to agree with Mr Clough that many of these narrow bands must be regarded as true dykes and not as contemporaneous veins. Those, too, of Linhope Spout behave clearly as dykes, maintaining a straight course and uniform thickness for some distance, and the rock resembles many of the dyke-rocks already described. Under the microscope [49] the margin of the band is seen to become very compact, and shows flow structure, while the junction with the granite is extremely sharp and well-defined. Granophyre groups are again of by no means uncommon occurrence [50]. The ground mass is microgranitic to cryptocrystalline, but may sometimes become micrographic. Similar vein-like dykes belonging to the acid series are common in the same neighbourhood [39], [41], [47].

There is no doubt, however, that many other small bands and threads of more acid material are to be regarded rather as contemporaneous veins, such as were squeezed into the granite previous to its complete consolidation, from a deeper-seated and more acid portion of the general magma. Thus several of the pink felspathic bands which traverse the granite in Linhope Burn, a short way below Linhope Spout, would seem to be of this nature. A hand specimen of one of them shows a fairly sharp line of demarcation at its junction with the granite. But under the microscope [38] this line becomes lost, the normal granite simply passing gradually into the vein-rock, while the latter only differs from the former in containing more quartz and orthoclase, less plagioclase, and scarcely a trace of ferromagnesian constituents. Another small vein, not more than half an inch in breadth, traversing the granite about a mile above Linhope, shows, however, a rather different structure under the microscope [40]. It consists entirely of quartz and orthoclase, with an occasional small pseudomorph after pyroxene. It is not particularly fine-grained in texture, though its junction with the surrounding rock is fairly sharp. In its central portion the orthoclase plays the rôle of groundmass to the quartz, but along the margins the two minerals have crystallised out simultaneously and form a beautiful micropegmatite of a branching dendritic type. This micropegmatite seems to have grown inwards all along the margin of the vein and at right angles to the junction line with the granite; so that the granophyric border appears to act with regard to the parent rock in the same characteristic manner as the micrographic groundmass of the granophyres acts with regard to the porphyritic crystals,

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i.e., when it forms about them the characteristic peripheral border. We may presume that the margin of the vein consolidated before the central portion. It is interesting, therefore, in connection with the relations of micropegmatite already discussed, to find here a quartz-felspar rock in which the formation of the micrographic structure was *followed* by the formation of the microgranitic. In this case the formation of the granophyric border may have been due to greater rapidity in cooling.

Small veins and dykes, traversing the contemporaneous lavas, are common in some places close to the granite margin. Thus, the Tathey Crags, about a mile SE. of Langleeford, consist of altered andesite traversed in all directions by numerous veins, varying in breadth from half an inch to several feet. Under the microscope [104], [105], [108], [109], they are seen to consist of medium-grained granite, resembling that of the main mass, microgranite and granophyre. In the granitic structure the quartz is of earlier consolidation than the orthoclase. In nearly all these veins, in addition to a fair amount of biotite, tourmaline is invariably present, and sometimes in considerable quantity. It is brown, bluish-green, or of a dark bluish colour, and usually occurs in irregular grains, or sometimes in short stout prisms. The characteristic pleochroism is strongly marked. One vein [105] contains this mineral in such quantity that one might call the rock a tourmaline granophyre. Tourmaline bearing granitic veins are again found in the neighbourhood of the granite margin in the altered andesite of the crags above Langleeford [95], [96], and in the Hen Hole [79].

Thus the chief distinguishing feature between these marginal veins and those within the granite area is the frequent occurrence in the former of tourmaline. I have also occasionally noticed it, as already stated above, in one or two of the granophyre dykes, traversing the granite, not far from its margin, and it occasionally occurs in the granophyres, which appear to form a marginal modification of the granite mass itself (see above, p. 37), and is not uncommon along lines of faulting.

I have now described the main petrological features of the principal varieties of dykes and veins in the Cheviot district. What I would specially call attention to is the large amount of different varieties of rocks which constitute these dykes, and the modifications which they show in texture, structure, and composition. Thus we may have augite-biotite-porphyrites, biotite-porphyrites, quartz-biotite-porphyrites, biotite-quartz-porphyries, orthoclase-porphyries or orthophyres, and granophyres, and these we find to be connected by intermediate

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varieties, showing a diminution in the proportion of certain constituents, and the increase or appearance of others, so that any strictly systematic classification of them is impossible.

I have already compared the dykes and sills of the intermediate series to the porphyrites associated with the granite masses of Criffel and Dalbeattie, described by Mr Teall, and Mr Teall finds a strong relationship to exist between these porphyrites and the granites which they traverse. And there is no doubt that the Cheviot porphyrites strongly resemble many of the dykes and sills connected with other granite masses of approximately the same geological age as the Cheviot mass, and now known as the Newer Granites of Scotland, as well as many of those traversing the contemporaneous rocks of other well-known volcanic areas of Lower Old Red Sandstone age.

In describing the dykes round the Shap Granite,[1] Mr Harker finds that the intrusions present a considerable range of differences, and have at the same time curious points in common. They have characters, moreover, which connect them on the one hand with the Shap Granite and on the other with the Mica-Traps. In the Cheviot district, too, we find that the dykes and sills not only have points in common, as I have endeavoured to point out, but show distinctive features which connect them on the one hand with the augite-granite, and on the other with the andesitic lava-flows which surround it. Thus the intermediate type of dyke-rock mainly consists of biotite-porphyrites containing more or less augite, which closely resembles the pyroxene so characteristic both of the granites and the andesites. Again, a rhombic pyroxene, presumably enstatite, occurs not only abundantly in the lavas, but also occasionally in the porphyrites and the granite. Pyroxene also sometimes occurs in the quartz-felsites and granophyres. The peculiar violet or bluish apatite is found not only in some of the andesites, but again occasionally in some of the later porphyrites. Micropegmatite may apparently appear in the ground mass of almost any of the Cheviot intrusives. In the less acid type of dyke it is not so common or so freely distributed when present; but it is certainly one of the most characteristic features not only of the more acid dykes but also of the more marginal portion of the granite. Further, the frequent occurrence of two generations of micropegmatite is an interesting feature of many of the dykes.

The following is an analysis of one of the more acid quartz-felsites, containing the granophyre-groups, from the river Breamish, a short way above Linhope, for which I am indebted to Mr Ivison Macadam of Edinburgh. I quote with it for com-

[1] Q.J.G.S., vol. xlvii. (1891), p. 287.

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parison the analysis of the biotite-quartz-felsite from the Coquet above Shillmoor, described by Teall:[1]—

	I.	II.
SiO_2	72·66	67·9
Al_2O_3	18·98	15·7
FeO	0·21	—
FeO_3	0·57	3·0
CaO	0·03	1·4
MgO	0·47	1·5
Na_2O	0·21	1·5
K_2O	5·91	5·6
SO_3	0·02	Loss 3·7
H_2O	0·86	—
	99·94	100·3

I. Quartz-felsite dyke, river Breamish, above Linhope.

II. Biotite-quartz-felsite dyke. River Coquet, half a mile above Shillmoor.

This analysis will probably represent that of the majority of the dykes that I have classed with the acid type, and it will be seen that they are thus considerably more acid than the variety rich in biotite, described by Mr Teall, while the latter has slightly higher proportions of lime, iron ores and magnesia.

I will now pass on to discuss certain considerations dealing with the relations between the various igneous rocks of this district.

4. *The Relation between the Granite, the Dykes, and the Andesites.*—The first period of volcanic activity in the Cheviot district was evidently marked by the eruption of immense quantities of andesitic lavas. They are mostly perfectly normal pyroxene-andesites showing little, if any, range of composition. No lavas of the rhyolitic type are known from this district, though it is possible of course that such may have been poured out at the surface during the later phases of the eruptive activity. This, which we may call the extrusive phase, was followed, as is proved by the phenomena of the granite and the dykes, by the intrusion of material partly of intermediate and partly of acid composition. This intrusive phase, which these phenomena characterise, commenced with the intrusion of the augite-granite into the contemporaneous lavas. That the granite was intrusive in the surrounding rocks was fully recognised by Mr Clough, and later by other observers,[2] and

[1] *Geol. Mag.*, Dec. 3, vol. ii. p. 107.

[2] See Sir Arch. Geikie, "Ancient Volcanoes of Great Britain," vol. i. pp. 337, 338.

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is, moreover, indisputably proved by the occurrence in the latter of contact metamorphic phenomena along the granite margin. The intrusion of the dykes and sills of porphyrite and quartz-felsite, since they cut, not only the andesites, but the granites as well, constituted therefore the latest phase of the volcanic activity of the district of which we have any record.

Mr Clough[1] considers the Cheviot granite as representing the deep-seated source of the andesites, and Mr Teall, in discussing this question, says,[2] "are these rocks (the granites) due to the consolidation beneath the surface of the magma which produced the andesitic lavas and tuffs? . . . The evidence available is not so complete as we could wish, but, such as it is, it points decidedly to an affirmative answer to the above question." Mr Teall's conclusion is partly based on the supposition that an analysis of the Cheviot granite would approximate very closely to those of the augite-granitites of Vosges, and he shows that there are close connections between the chemical analyses of these latter rocks and those of the Cheviot andesites. I would point out, however, that the analyses that I have already given of two samples of Cheviot granite, one of which I certainly think approximately represents the normal type, both show a considerably higher silica percentage than that of either the andesites or the granites of the Vosges. Further, as regards the alkalies, there is a well-marked excess of potash to soda, whereas the converse is the rule in the normal andesites.

These considerations, I think, would rather seem to show that if, in the granite, we are dealing with the deep-seated source of the andesites, it can only be in a very limited sense. It seems more probable that we have here a portion of the original andesitic magma, which had undergone a certain amount of differentiation previous to intrusion. The granite is on the whole distinctly more acid than the lavas and belongs to a later phase of activity.

As regards the amount of differentiation which the mass shows, this is apparently by no means so great as one might have expected from the very varying aspect of the rocks. Where a slightly more basic modification does occur, as in the neighbourhood of Linhope, it is marginal. This is, however, by no means a uniform, but rather a local character, many of the marginal varieties of rock from other portions of the area appearing, if anything, more acid than the normal type. A somewhat similar type of marginal variation may

[1] Mem. Geol. Survey, "The Cheviot Hills," p. 24.
[2] *Geol. Mag.* (1885), p. 117.

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perhaps be found in the case of the granitic rocks of Garabal Hill and Meall Breac, described by Messrs Dakyns and Teall.[1] Here, however, the formation of a basic modification had proceeded to a far greater degree. In the present case the amount of variation exhibited appears hardly to be sufficient to be of any great importance, in comparison with the many examples of extreme variation in igneous masses which have been previously described. The occurrence, nevertheless, of augite-granitites, granophyres, and contemporaneous felspathic veins, as constituents of our granite mass, will suffice to show that a distinct amount of differentiation had taken place in the magma subsequent to the extrusion of the andesitic lavas.

But let us see, now, how the phenomena of the dykes and sills bear upon the sequence of events in the igneous activity of this area.

Mr Clough observed[2] that the majority of the dykes tend to have a more or less radial arrangement and to point towards the central part of the granite area, and this is at once seen on glancing at the Survey map of the district. Similar instances are, however, not uncommon in other localities. Thus J. P. Iddings has described radiating dykes converging upon a central mass of granular gabbro, which graduates into diorite, in the volcanic area of Crandall Basin, in Wyoming.[3] Radial dykes are also well seen, according to Pirsson, in the Crazy Mountains,[4] and in the Highwood Mountains of Montana.[5] The latter author points out that these dykes represent the very latest phase of the eruptive activity, and that the rocks composing them are more highly differentiated than those of the central masses. Pirsson supposes that such dykes originated owing to cracks being formed by the cooling and consequent contraction of the central mass. Cracks would thus occur also in the heated zone of surrounding rocks, and if these are homogeneous, the cracks will be more or less radial. Radiating fissures, he points out, are most typical, where intrusions have taken place into areas of approximately homogeneous and undisturbed strata. Again, the same author finds that these radial dykes are generally composed in the same district of two main groups, which he terms lamprophyres and oxyphyres, indicating the more basic and more acid series respectively. These constitute "complementary" groups, and the more basic types are usually found further from the centre than the more acid. This we

[1] Q.J.G.S., vol. xlviii. (1892), p. 104.
[2] Mem. Geol. Survey, "The Cheviot Hills," p. 28.
[3] *Geol. Mag.* (1893), p. 559.
[4] Bull. Geol. Soc. Am., vol. iii. (1892), p. 451.
[5] *Op. cit.*, vol. vi. (1895), pp. 389-422. See also *Am. Journ. Sci.*, 3rd Series, vol. l. pp. 116-121.

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should expect, on the supposition of the magmatic differentiation having been mainly determined by the migration of the more basic constituents towards the outer margin.

In the Cheviot district it would seem that we have a somewhat parallel case to those described by Pirsson, with certain modifications. We have numerous dykes showing a more or less radial arrangement, and traversing a thick series of approximately homogeneous and undisturbed andesitic lava-beds, and representing moreover the final phase of the eruptive activity of the district. Taken together, these dykes show more extensive differentiation than the main mass of granite.

I have already drawn attention above to the range of composition exhibited by the dykes. Thus we have every gradation from an intermediate rock with strong affinities to the andesites to a distinctly acid rock showing relations to the more acid granites and granophyres of the central area. And since the less acid variety of the granite is considerably more acid than the mica-porphyrites, we have then a greater divergence of differentiation at the time of the infilling of the radial fissures. It is also true to a certain extent that the quartz-felsite and granophyre dykes are most numerous in and about the central core. The porphyrite dykes, however, as we have seen, do not always occur away from the centre, but are frequently seen cutting the granite mass as well.

From these considerations I think, perhaps, we are justified in concluding that the quartz-felsites and porphyrites of the Cheviots are "complementary" rocks, and represent the extremes of a series derived by a process of differentiation from one original magma. It might be urged, however, that if the original magma was of an intermediate composition, we should expect to find more decidedly basic modifications of it among the dykes, and basic dykes are not known as products of the igneous activity of this district. Still there is no reason why such should not have been formed beneath the surface, but not tapped during the dyke-forming phase. And further, the observable succession of igneous rocks in a volcanic area is well known to be of a very varying nature, and at present no general law has been formulated which will apply to all cases alike. No doubt the extremely varying nature of the physical conditions which obtain in different areas, will account for a good many of the apparent discrepancies observed.

Still, however this may be, the study of the petrological features of the Cheviot igneous rocks brings one unhesitatingly to the conclusion that the source of supply for the andesitic lavas, the granites and the dykes and sills, was the same. We cannot ignore the close relationships that have already been

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pointed out that exist between the three groups of rocks. The structural differences between them are no doubt due to differences in the conditions of consolidation. The variation observable in the granite mass, and the range of composition shown by the dykes, I would attribute to differentiation in the original magma, probably determined to a great extent by the action of progressive crystallisation, as already pointed out by Mr Teall[1] in dealing with the relations of quartz-felsite to andesite.

And if we have in the Cheviot rocks fair samples of all the variations formed in the original magma, the degree of variation in the granite and the dykes will show us the corresponding amount of differentiation, which had been produced at the time of the intrusion of these rocks respectively.

Apparently, a progressive differentiation gradually went on in the original homogeneous magma, a partial result of which we see in the granite, while a further stage is indicated by the dykes. As to how far the illustration is complete, we have no means of judging.

At any rate, it seems certain that in the Cheviot district we are dealing with three distinct and successive phases, belonging to the same geological period, of one original magma: an extrusive phase, characterised by outpourings of andesitic lavas; a plutonic phase, characterised by the intrusion of the granite; and the fissure or dyke phase.

In conclusion I would point out that the central granite mass, as suggested by Sir Arch. Geikie,[2] very probably occupies the site of the main focus of the volcanic activity of this district, and that it has thus been intruded into the lower portion of the old vent or group of vents from which the surrounding andesitic lavas were discharged.

The volcanic cone of Lower Old Red Sandstone times, which reared itself where Cheviot and Hedgehope Law now stand, has long since passed away. But the ceaseless action of denudation has laid bare for us the very heart and core, so to speak, of this ancient volcanic pile, with its surrounding accompaniment of associated dykes. And it is this which has made the Cheviot district unique amongst the volcanic areas belonging to the same geological period.

I am aware that the above account of the petrological phenomena and relations of these interesting rocks cannot profess to be complete, and that there are many questions still left unanswered. We can only hope that further research will throw

[1] *Geol. Mag.* (1885), p. 118.

[2] Q.J.G.S., vol. xlviii. p. 87; also "Ancient Volcanoes of Great Britain," vol. i. p. 338.

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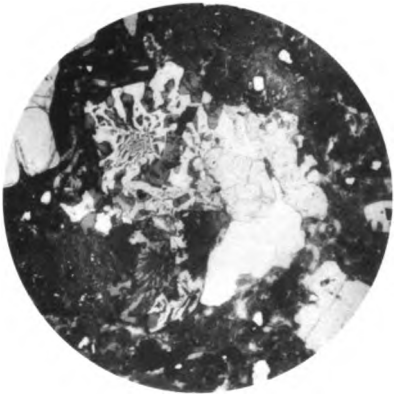

Fig. 1.

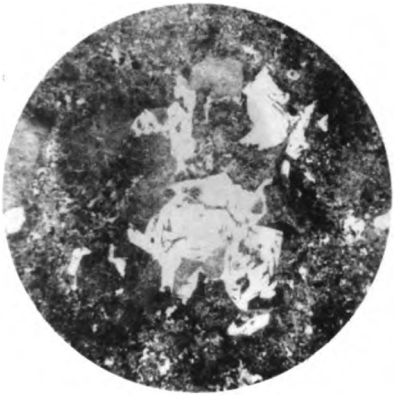

Fig. 2.

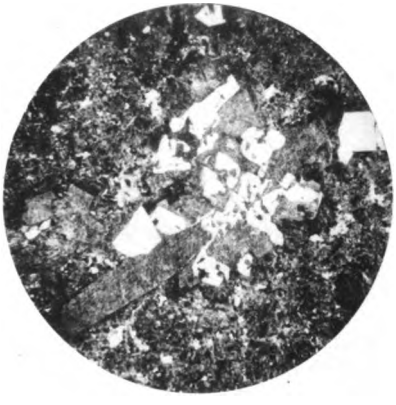

Fig. 3.

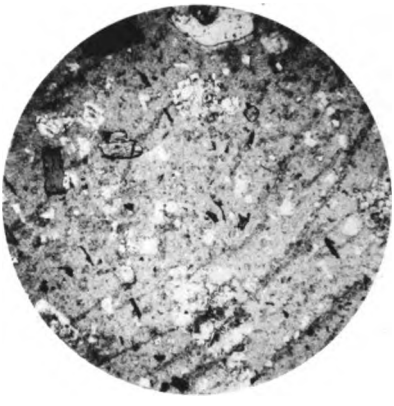

Fig. 4.

Photo-Micro.—H. Kynaston.

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more light on many of the interesting problems connected with volcanic areas, and we feel sure that in this branch of geology there is still a very wide field of investigation for the comparative petrologist.

EXPLANATION OF MAP.

Lower O. R. S.

- *G*—Granite.
- *A*—Andesite.
- *Ts*—Tuffs.
- *P*—Porphyrite (dykes and sills).
- *F*—Quartz-Felsite.
- $d^{1\text{-}3}$—Carboniferous.

EXPLANATION OF PLATE.

FIG. 1. Phenocryst of micropegmatite in Rhyolite, from Schemnitz, Hungary.

FIG. 2. Phenocryst of micropegmatite in Quartz-Felsite, from R. Breamish, Cheviots.

FIG. 3. Phenocryst of micropegmatite in Quartz-Felsite, from R. Breamish, Cheviots.

FIG. 4. Section of Porphyrite, with phenocrysts of plagioclase, biotite, augite, enstatite, and micropegmatite, from Dunmoor Hill, Cheviots.

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LIII.—*Geological Notes on Strathdearn and the Aviemore Railway.* By THOMAS D. WALLACE, Inverness.

(Read 17th March 1898.)

PART I.

THE construction of this new railway, now nearly completed, which extends from Aviemore on the Highland Railway to Inverness, by Moy Hall, has opened up some new geological sections. Having on previous occasions communicated to the Society some observations on the geological features in the neighbourhood of Inverness, I have been watching the operations on this line of railway, expecting to have some further light thrown upon the geology of Strathnairn, and particularly on its fossil remains. Although very little of importance has turned up, yet the few notes now communicated may not be wanting in interest.

Before stating the results of my observations, it may be of importance to describe in a few sentences the topography of the route.

Leaving Inverness from the present railway station, the shore is skirted for a short distance, then with a sharp curve to the south the line passes through the 90 feet terrace, and emerges upon a fine, open, cultivated country, after which it enters the woods to the south of Culloden House. The first station from Inverness will be at Culloden Moor, a short distance from the battlefield.

Strathnairn is crossed by a magnificent stone viaduct, and the line rises gradually along the hillside to the south of the Nairn River, till Craggie is reached. From Craggie to the Findhorn the route is over comparatively level ground, passing Moy Hall on the shore of Loch Moy.

The Findhorn is crossed by another very fine piece of engineering in the shape of a viaduct supported on Aberdeen granite pillars. After leaving the Findhorn the line passes through the Pass of Slochmuick, before descending to Carrbridge. From Slochmuick the lover of scenery will be rewarded by a view of the Grampians that cannot be surpassed. From Carrbridge to Aviemore the route is over a flat district, beautifully wooded with pine and birch. The scenery on this line will be the finest in the Highlands, while its historical and archæological features have already engaged the attention of scientists.

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Throughout its entire length the cuttings have been through the drift deposits. Only in one or two places has the rock been reached, viz., Old Red Sandstone at Culloden Moor and Gneiss at Craggie and Slochmuick. The drift deposits consist of sand, gravel, and boulder clays.

At Millburn, near Inverness, the first cutting is through the 90 feet terrace, which discloses a section of fine stratified sand and gravel overlying in one place an arranaceous grey clay, which was found after careful washing to be destitute of organic remains. The next cutting was in Culloden woods, which was through boulder clay.

Between Millburn and this point many interesting boulders of granite, conglomerate, and porphyry were found in the clay, and showing in themselves fine striation and glaciations. The granite boulders were from the west, and some from Stratherrick. One fine conglomerate boulder was undoubtedly from Inverfaragaig. These with other western rocks confirm the theory that the ice-flow was from SW. to NE., or along the line of the great glen and the Moray Firth.

Several fragments of the black fossiliferous shale were also found, showing that the denudation had reached that depth in the O. R. formation in this neighbourhood.

One curious fact might be mentioned, which is as follows:— On the top of the north embankment of this cutting, and on the very edge of it, there was a well which supplied by means of pipes a house at a distance. When the cutting was made the water left the well, and the Railway Company had to lay down a fresh supply of water to the house. Not long after this was done the water returned to the well, and remains there. In this section great trouble was experienced with a copious flow of water from the south bank. This may be explained by the dip of the rocks being towards the NW., and the water that collects on the flat moor to the south flowing naturally down the dip of the strata was intercepted by the cutting.

At Culloden Moor the rock was reached but only touched. A considerable quantity of sandstone was quarried here, and the section showed first 10 feet of boulder clay, then 5 feet of broken sandstone mixed with boulder clay. This was followed by 15 feet of shattered rock overlying the solid rock, which showed a dip of 15° to 25° NW., the normal dip of the strath.

A bed of fossiliferous shale was cut through which showed fragments of organic remains in the shape of fish scales and plants. When sinking the piers of the viaduct over the Nairn, the pier on the north bank of the river was founded easily on the rock which appears at the surface and shows another bed of

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bituminous shale, but no solid foundation could be found for the pier on the south side, although the two were separated only by a few yards.

The contractor had a similar experience at the Findhorn viaduct. This may possibly indicate the bed of an old pre-glacial river. It could scarcely be a fault, as the junction of the O. R. Sandstone with the Gneiss is seen at no great distance from the spot, in Dalroy Burn, where the conglomerate lies unconformably on the Gneiss, and dips to the NW. at the usual angle.

Another very fine section of rock was displayed in Lienach Quarry, out of which the stone for the Nairn viaduct was taken. The section shows from 10 to 20 feet of boulder clay overlying 20 to 25 feet of broken or crushed rock, underneath which there is 50 feet of solid rock exposed in the section, without any trace of fossils. There is a good deal of false bedding, with a general dip of from 15° to 25° NW.

At one part a decided slip or fault can be traced the whole depth of the exposed face. The vertical section of the fault looks as if the rock had parted, and the intervening space between filled up with broken rock; but it is in all probability the shattering of the rock caused by the downthrow.

On looking across the river from this point several well defined river-terraces can be traced on the hillside, behind one of which the now famous Clava Shelly clay rests.

There was a slight cutting into the Gneiss at Craggie station, which showed the usual contortions with quartz and granite veins running throughout the mass. A good grey granite quarry was opened by the Railway Company a little to the south of Craggie, and the stone used in their building operations.

Below Craggie station, and to the south of it, are the finest specimens of glaciation to be seen anywhere in the whole valley.

There are also on both sides of the Nairn here large accumulations of sand and gravel, especially above the bridge and to the south of Faillie, where they assume immense ridges, now covered with young wood. These must be taken into account when considering what we are about to describe.

The flat over which the railway runs from Craggie to the Findhorn is, by a consensus of opinion, based upon minute examination of the ground by several observers, to be the basin of an old glacial lake.

Previous to the gorge known as the "Streens" on the Findhorn, within the area of this old lake, being cut through, the channel of the Findhorn must have run in the direction of Craggie. When glaciers began to accumulate and flow down from the

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valley of the Findhorn their tendency would be to cut through this old channel and force a way in the direction of the present Findhorn channel. As the glacier retired the water would accumulate in the hollow, which would at first be chiefly drained into the Nairn valley.

As the cutting at the Streens became deeper it would be partly drained towards that opening. As the water lowered the lake would be divided by the accumulation of gravel and boulder clay which occupies the watershed by the old lake. The western part now occupied by Loch-a-Churin would drain into the Nairn, and the east, now occupied by Loch Moy, would drain into the Findhorn, as they do at present.

There is a well-defined ridge of gravel and sand at the east end of Loch Moy, which must for some time have formed a barrier to its waters at that end. A rise of about 90 feet would send the waters of the Findhorn out by the old channel into the Nairn.

About 10 miles above Freeburn on the Findhorn there are great accumulations of sand and gravel similar to those on the north of the "Streens," as well as portions of well-defined terraces at various levels. The accumulations of sand in the Nairn Valley at Craggie and above the bridges were, in all probability, formed under the waters of a glacial lake formed by the detrital matter carried down the channel of the pre-glacial river from the Findhorn Valley and deposited before the gorge at Daviot was cut through.

The whole of the Nairn Valley was at one time submerged to the depth of 500 feet and more, as proved by the Clava Shelly clay. When the land began to rise the height at Craggie and Freeburn would gradually appear; and as this would give rise to currents, the moraine matter would get rolled and washed —the sand finding a resting place in the deeper and quieter waters, and the larger materials arranged in ridges and terraces.

The sand and gravel on all watersheds that I have examined are arranged in conicle mounds of various sizes; and this holds good at Daviot to the NW. of Craggie.

The new line has exposed some sections of boulder clay and Gneiss between the Findhorn and Carrbridge; and between the latter and Aviemore it runs entirely through gravel.

It was hoped that the various sections of this line would have thrown some additional light upon the extinct O. R. fauna and on the Arctic clay deposits; but in both these respects we have been disappointed.

Undoubted confirmation, however, has been obtained by the NE. flow of the last glaciers that filled the valleys of the Nairn and the Findhorn.

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LIV.—*On Carbonia: its Horizons and Conditions of Occurrence in Scotland, especially in Fife.* By Professor T. RUPERT JONES, F.R.S., Assoc. Geol. Soc., Edinb.; Mr JAMES W. KIRKBY; and Dr JOHN YOUNG, F.G.S., Assoc. Geol. Soc., Edinb.

(Read 7th April 1898.)

MANY years ago[1] the late Professor W. C. Williamson expressed some surprise that the little Entomostracan shells abundant in some of the Carboniferous strata should have been so frequently referred to as indicating the existence of fresh water. Of course, our deceased friend could himself have given the explanation, namely,—because the particular strata of Burdiehouse, and other such Carboniferous limestones and shales, were regarded as being of fresh-water origin,[2] chiefly on account of the absence of marine organisms, the presence of many terrestrial plant-remains, and some peculiar fishes. Hence the genus *Cypris* (Müller, 1785), being the best-known of freshwater Ostracods, was the more readily taken by Geologists as analogous to the fossil forms in such strata as the above-mentioned.

So-called fossil "*Cyprides*" were mentioned by Desmarest, 1813; J. Sowerby, 1824; Hibbert, 1834; J. de C. Sowerby, 1835, 1836, 1840; Bean, 1836; Williamson, 1836; Phillips, 1842; Portlock, 1843; Dunker, 1846.

The fossil Ostracoda of marine strata were referred to "*Cythere*" (Müller) by Münster, 1836; Römer, 1838; de Koninck, 1841; Reuss, 1844; Cornuel, 1844; M'Coy, 1844.

Subsequently generic differentiation improved the grouping of the fossil forms, both of the *Cyprididæ* and *Cytheridæ*;—and, as far as the comparison of the tests could serve, the analogies and identities were more and more clearly determined.

Some, however, of the Ostracods in the Carboniferous series of beds, though usually found in what are regarded as "freshwater" strata, present themselves also in association with fossils of marine origin. There is (1) a dwarf variety (*Scotoburdigalensis*) of the specially marine *Leperditia Okeni*[3]; and (2)

[1] Manchester Literary and Philos. Soc. Memoirs, vol. viii. (1847), p. 89.
[2] As he intimated in the *Philos. Mag.*, new series, vol ix. (1836), p. 352.
[3] See Ann. Mag. Nat. Hist., ser. 3, vol. xvii. (1866), p. 35.

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several species of *Carbonia*. The first, however, may bear evidence of having been modified by migration into brackish or estuarine water; and the latter seem to have flourished most generally in waters which were not frequented by the animals of the sea; but also to have had sometimes marine creatures for their associates; and so far, this is evidence of their having been capable of living in both fresh and salt water.

Seven species (together with their varieties) of *Carbonia* were fully described and illustrated in 1879. Two species (and varieties) had already been determined. Three other species have been since referred to the genus, making twelve in all, as enumerated below:—

1. Carbonia fabulina, Jones and Kirkby, Ann. Mag. N. H., ser. 5, vol. iv. (1879), p. 31, pl. 2, figs. 1-5 and 7-10.
   ——— ——— var. humilis, *Ibid.*, figs. 11-14.
   ——— ——— var. inflata, *Ibid.*, figs. 15-19.
   ——— ——— var. subangulata, *Ibid.*, figs. 20-23.
   ——— ——— var. ovalis, nov., *Ibid.*, fig. 6.
2. ——— Rankiniana, J. & K., *Ibid.*, p. 34, pl. 3, figs. 1-8.
3. ——— subula, J. & K., *Ibid.*, p. 35, pl. 3, figs. 9-13.
4. ——— scalpellus, J. & K., *Ibid.*, p. 36, pl. 3, figs. 14-17.
5. ——— secans, J. & K., *Ibid.*, p. 37, pl. 3, figs. 18-20.
6. ——— pungens, J. & K., *Ibid.*, figs. 21-23.
7. ——— Evelinæ, Jones, *Geol. Mag.*, vol. vii. (1870), p. 218, pl. 9, fig. 4.
8. ——— Agnes, Jones, *Ibid.*, fig. 6.
   ——— —— var. rugulosa, *Ibid.*, figs. 8, 9.
   ——— —— var. rubengulosa, *Ibid.*, fig. 10.
9. ——— bairdioides, J. & K., A.M.N.H., *l.c.* p. 38, pl. 3, figs. 24, 25.
10. ——— Wardiana, J. & K., A.M.N.H., ser. 5, vol. xviii. (1886), p. 265, pl. 9, fig. 10.
11. ——— Roederiana, J. & K., Trans. Geol. Soc. Manch., vol. xxi. (1891), p. 138, fig. 5, 6.
12. ——— Salteriana, Jones, *Ibid.*, p. 140, figs. 11, 12.

Since a sketch of the conditions under which these particular Ostracods seem to have lived, and of the localities where they are now found, must be of interest, this paper has been prepared with all the information we have collected on the subject.

Desirous of finding what evidence Ostracoda yield in distinguishing deposits of different origin, whether in salt,

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brackish, or fresh water, the Entomostraca in the strata of the Campsie district, near Glasgow, have been noted by Dr John Young; and the occurrence of different genera and species in the Carboniferous series of Fifeshire has been examined, and the results tabulated by Mr J. W. Kirkby.

In his memoir "On the Geology of the Campsie District" (Trans. Geol. Soc. Glasgow, vol. i. pp. 1-68), Dr J. Young describes those Lower Carboniferous limestones and shales to which he ascribes a freshwater or estuarine origin, at the Linn of Baldarnock (p. 31); also in the Millburn series (p. 32), the Craigenglen series (p. 34), and the Hosie Limestone series (p. 35). These beds, he observes, are marked by the absence of marine fossils and by the presence of plant-remains.[1] Their characteristic Ostracod is *Carbonia* (formerly "*Cythere*") *fabulina*. This swarms in thousands, both here and in the Calder Coalfield; often massed in such abundance as to constitute the material of the oil-shales,[2] which are evidently made up of the crushed and still partly transparent shells of *Carbonia*. In the associated limestone *Carbonia fabulina*, *C. pungens* and *C. secans* are found in a less crushed condition.

In the third edition of this memoir (1894), Dr Young uses the term "lacustrine" instead of "estuarine," no marine form having been recognised in these beds. He states: "we have the *Carbonia* group present in abundance in various kinds of strata, such as white and ferruginous limestones, clay-ironstones, carbonaceous and clay (purely argillaceous) shales. Mixed with them we sometimes find the remains of ganoid fishes of lacustrine types; and the coprolites of some of them show that they had lived largely on the *Carbonicæ* then swarming in the waters. Shells of *Anthracosia* (the 'Unio' type of the coal), with land-plants and *Spirorbis* of lacustrine type, are present in some of the beds. I do not think that I ever met with *Carbonia* in strata holding typical forms of marine life."

Dr John Young, moreover, informs us that he has found *Spirorbis* (*Microconchus*) *carbonarius*, Murchison, in two of the *Carbonia* limestones ("lacustrine") of the Lower Series of the Campsie district; in these limestones no marine organisms (as far as he knows) have been identified.

"From our Upper Coal-measures of Lanarkshire" (he writes)

[1] It was on this basis that Dr S. Hibbert wrote his elaborate treatise on the Freshwater Limestone of Burdiehouse. Transac. Royal Soc., Edinburgh, vol. xiii., 1836.

[2] Some black shale of the Carboniferous series in Tyrone and Londonderry, Ireland, containing relics of *Dithyrocaris Colei*, are mainly composed of small compressed Octracods (possibly *Carbonia*), like some of the oil-shales of Scotland here referred to. See Monogr. Brit. Pal. Phyllop., Pal. Soc., Part iii., 1898,

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"I have the same species of *Spirorbis* from three localities; in one instance being on the stems of plants; in another on shells of *Anthracoptera*; and, in the third, in a piece of the Airdrie black-band ironstone noted for its remains of Ganoid Fishes.

"Our other 'lacustrine' species of *Spirorbis* (*Microconchus helicteres*, Salter) is found at two places: one at the Heads of Ayr, on the Clyde, in 'lacustrine' calciferous strata; the other in the Upper Coal strata at Newton, east of Glasgow, in what is termed a Mussel-band ironstone; where it is associated with thousands of *Anthracosia*." Dr Young also remarks that "The Geological Survey of Scotland, in the 'Memoir, Explan Sheet 25 (Lanarkshire, central district),' in the list of fossils, notes the occurrence of *Spirorbis carbonarius* at some other localities and horizons. Other localities are also given in the list of fossils for 'Sheet 31.' This species, therefore, seems to have been not uncommon in the 'lacustrine' strata of the Upper Coal-measures of western Scotland; as also in similar strata in the Millstone Grit series."

Dr J. Young once found a well-preserved set of *C. fabulina* filling the hollow stem of a *Lepidodendron* branch that had come from the Possil Ironstone, near Glasgow. This interesting occurrence specially points to the floating of a decaying branch in a quiet inland water.

In the "Transactions of the Geological Society of Glasgow," vol. x., part 2 (1896), pp. 334-336, he gives the results of a microscopic examination of the Craigenglen "lacustrine" limestone, on the South Hill of Campsie and belonging to the Lower Limestone series.

"In sectioning some portions of the limestone, which showed externally to the naked eye a minute brecciated structure, I was very much interested to find that it frequently had single valves of the shells of the Ostracoda [1] collected into neat little nest-like groups containing from two to nine or more specimens in each. They were often closely assorted in size and form, one within and above the other, like piles of saucers, in little crevices between the fragments of the breccia, and were surrounded with a matrix of calcite, which, subsequently infiltered, had cemented the fragments of the breccia together. The shells, it may be stated, are generally well preserved, their thin and delicate valves being neither crushed nor distorted. In looking over the sections, one is struck with interest at the

[1] Five species of *Carbonia* have been found in this stratum by Dr J. Young. See the List of Carboniferous Ostracoda in the Trans. Geol. Soc. Glasgow, vol. ix. (1893), p. 311.

In Dr J. R. S. Hunter's "Palæontology of the Carboniferous Strata of the West of Scotland," Part 2, 1875, at pages 17, 21, 25, 27, 38, 39, 48, and 77, enumerates seven species of *Carbonia* with their localities and horizon.

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great regularity in this arrangement of the valves, both in relation to size and shape. This peculiar feature distinguishes this variety of the limestone from all other parts of the rock in which the Ostracoda exist, and from which the brecciated structure is absent.

"The occurrence of these nest-like groups has suggested to my mind, as an explanation, that the dead shells were drifted by gentle currents of water from portions of the lake-bottom to other tracts where the sediments had been for a time laid bare through a retreat of the waters. These sediments, under the drying power of the sun, would be minutely cracked and fissured, as seen along many lake-shores at the present day; and into such openings the valves of the Ostracoda would be swept by the returning waters, the currents having probably some assorting and selecting power which gave them, according to size and shape, the neat arrangement in which they now lie. They were then preserved from crushing or distortion by the after-infiltration of a soluble calcite into the fissures.

"Since I first discovered this nest-like arrangement of the Ostracoda which I have now endeavoured to describe, in the brecciated limestone at Campsie, I have looked for a similar occurrence in other lacustrine limestones where shells of the family abound, but have not been able to detect it in any of them. This seems to indicate that before such an arrangement of the shell-valves could have taken place some such conditions as those I have supposed above must have existed in producing (1) the fissuring of the mud bed (brecciated rock), and (2) the introduction of the shells of the Ostracoda into the fissures through the action of a current of water."

Mr J. Neilson, in the Trans. Geol. Soc. Glasgow, vol. x., part 1 (1894), pp. 61-79, treating of the "Calderwood Limestone and Cement-stone with their associated Shales" and their fossils, remarks (p. 66, etc.) that the East Kilbride Cement-stone "is of genuine estuarine origin," and that the so-called "estuarine" strata of the Upper Coal-Measures present insufficient evidence of marine organisms to be grouped under that term, and should be regarded as of freshwater origin.

It will be afterwards seen, from the results of Mr Kirkby's researches, that *Carbonia* ranges from the lowest strata to nearly the highest in the Carboniferous Series of the East of Scotland. In England (Northumberland excepted) none of its species have as yet been found below the Coal-measures; though in them they are common fossils, even probably at higher horizons in Lancashire and the Midland Counties than in Scotland. It is not rare in some of the Coal-shales in South

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Wales. It has not yet been recorded from the Carboniferous strata of Ireland, but will probably be found among its coal-beds.

Some of the British species of *Carbonia* have been met with in the coal-series of West Virginia, and in the Lower Carboniferous rocks of Nova Scotia. But it is certainly strange that no members of the genus are as yet known from any of the Continental Coalfields of Europe.

Remarks by Mr Kirkby.

In Fife the Carboniferous rocks form a thick series of strata, easily studied in fine, natural coast-sections. These take in fully three-fourths of the whole formation; and what is wanting —mainly the middle or coal-bearing portion of the Carboniferous Limestone series—can be obtained from sections recorded in sinking to the coals of the latter subdivision. Hence we arrive at a fairly complete and detailed knowledge of the sequence of the strata from the highest "Red beds" of the Coal-measures down to the lowest exposed beds of the Calciferous Sandstones. Species of *Carbonia* range through nearly the whole of these strata; and the following synoptical account shows the localities and horizons at which *Carboniæ* have been noticed to occur; the nature of the stratum and associated fossils in each case being also given. The approximate position of the horizons is shown in feet below the Red Sandstone seen to the west of the River Leven, which is the highest bed of the Carboniferous series known in Fife. These results have been arrived at mainly from personal examination, except for the beds included in the Millstone-grit and Lower Coal and Ironstone series, for which portion the published vertical sections of the Geological Survey have been used.

Occurrences of *Carboniæ* in Fife.

Coal-measures.

	Feet.
1. In blackband ironstone. Coast, west of Methil .	416
Carbonia fabulina, J. & K., C. Rankiniana, J. & K., C. secans, J. & K. Associated with *Leaia Leidyi* (Lea); *Spirorbis carbonarius*, Murch.; Palæoniscid scales and other fish-remains; and Stigmarian rootlets.	
2. In a band of reddle. Coast, west of Methil . .	443
Carbonia Rankiniana, J. & K.,—very abundant. Associated with Palæoniscid scales and other fish-remains.	

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3. In red and grey shale. Coast, west of Methil. . 463
CARBONIA RANKINIANA, J. & K. Associated with a dwarfed form of *Anthracomya*; Palæoniscid scales and teeth; *Lepidodendron* sp., and *Calamites* sp.

4. In shale and ironstone nodules overlying the Eight-Foot Coal, Durie and Leven Collieries, near Leven 1580
CARBONIA FABULINA, J. & K. Associated with species of *Anthracosia*, *Anthracoptera*, and *Anthracomya*; *Spirorbis carbonarius*, Murch.; and Plant-remains.

5. In parrot coal. Pirnie Colliery, near Leven . . 2060
CARBONIA FABULINA, J. & K., C. RANKINIANA, J. & K. Associated with *Megalichthys Hibberti*, Ag., *Strepsodus sauroides*, Ag., and other fish-remains; *Anthracomya* sp.; *Spirorbis carbonarius*, and Plant-remains.

6. In black shale. River Leven, near Kirkland Dam .
CARBONIA FABULINA, J. & K. Associated with *Anthracomya* sp.; and macrospores.

7. In parrot coal. Earl David's Parrot Coal, Trial Pit, East Newton, Wemyss 2163
CARBONIA FABULINA, J. & K.

8. In shale about sixty feet above the Dysart Coal, Wellsgreen Colliery 2600
CARBONIA FABULINA, J. & K. Associated with *Anthracosia robusta* (Sow.).

CARBONIFEROUS LIMESTONE SERIES.

9. In ironstone bands, twelve feet below the Levenseat Limestone, east of Ravenscraig Castle, near Kirkcaldy 3650
CARBONIA FABULINA, J. & K. Associated with *Calamites* sp.

10. In blackband ironstone. Lochgelly Colliery . . 4843
CARBONIA FABULINA, J. & K. Associated with the teeth of *Rhizodus Hibberti*, Ag.; *Spirorbis* sp.; and *Lepidostrobus* sp.

11. In blackband ironstone, above the Five Feet Coal, Hill of Beath Colliery 5400
CARBONIA FABULINA, J. & K. Associated with *Rhizodus Hibberti*, Ag. (teeth), and other fish-remains.

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CALCIFEROUS SANDSTONE SERIES.

12. In blackband ironstone. Coast, west of Pittenweem 6688

CARBONIA FABULINA, J. & K., C. RANKINIANA, J. & K. (robust examples of both species). Associated with *Leperditia Scotoburdigalensis* (Hib.); *Anthracomya Scotica*, Eth.; coprolites, and *Lepidodendron* sp.

13. In shale and ironstone bands. Coast, west of Pittenweem 6798

CARBONIA FABULINA, J. & K., and var HUMILIS, C. PUNGENS, J. & K., C. RANKINIANA (?), and C. sp. Associated with *Leperditia Scotoburdigalensis* (Hibbert); *Anthracomya Scotica*, Eth.; Palæoniscid scales; *Calymmatotheca affinis* (L. & H.), and macrospores.

14. In ironstone bands (in shale). Coast, near the east end of Pittenweem 8079

CARBONIA, sp. Associated with a species of *Beyrichia* (the prevailing fossil) and *Leperditia Scotoburdigalensis* (Hib.), and Palæoniscid scales and teeth.

15. In a cement-stone band and dark shale. Coast, east of Pittenweem 8180

CARBONIA RANKINIANA, J. & K., C. SUBULA, J. & K. Associated with *Leaia Leidyi* (Lea); *Myalina* (?) *modioliformis*, Brown; Palæoniscid scales; and *Lepidodendron* sp.

16. In an ironstone band. Coast, east of Pittenweem . 8206

CARBONIA SUBULA, J. & K. Associated with *Leperditia Scotoburdigalensis*, a few fish-remains, and traces of Plants.

17. In shale and ironstone bands. Coast, east of Pittenweem 8308

CARBONIA FABULINA and var HUMILIS, J. & K., C. RANKINIANA, J. & K., C. PUNGENS, J. & K. Associated with *Leperditia Scotoburdigalensis* (Hib.), and *Kirkbya spiralis*, J. & K.

18. In ironstone nodules. Coast, east of Pittenweem . 8325

CARBONIA SUBULA, J. & K., C. FABULINA, J. & K., C. BAIRDIOIDES (?), J. & K., C. RANKINIANA (?), J. & K. Associated with an Aviculoid shell; and *Calymmatotheca affinis* (L. & H.).

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19. In dark shale and ironstone bands. Coast, east of Pittenweem 8439

CARBONIA SUBULA, J. & K., C. FABULINA, J. & K., C. RANKINIANA (?), J. & K. Associated with *Calymmatotheca affinis* (L. & H.).

20. In dark, laminated shale with ironstone bands. Coast, east of Pittenweem 8558

CARBONIA FABULINA, J. & K. Associated with Palæoniscid scales and teeth, scales of *Rhizodopsis* sp.; *Spirorbis* sp.; *Lepidodendron* sp.; and *Lepidophyllum*.

21. In tough black shale. Coast, west of Billow Ness . 8816

CARBONIA RANKINIANA, J. & K. Associated with the scales of *Rhizodus Hibberti*, Ag. (encrusted with *Spirorbis* sp.), Palæoniscid scales; *Lepidodendron* sp., *Lepidophyllum*, *Carpolithes* sp., and *Cyclopteris flabellata*, Brongn.

22. In ironstone nodules in grey shale. Coast, west of Billow Ness 8993

CARBONIA SUBULA, J. & K., C. FABULINA, C. RANKINIANA, J. & K. Associated with traces of Plants.

23. In shale and ironstone bands. Coast, west of Billow Ness 9090

CARBONIA SUBULA, J. & K., C. FABULINA & var HUMILIS, J. & K., C. RANKINIANA, J. & K. & var. Associated with *Cytherella extuberata*, J. & K., *C. attenuata*, J. & K., *C.* sp. indet., *Beyrichia* sp., *Cythere superba*, J. & K.; and *Myalina* (?) *modioliformis*, Brown.

24. In dark fissile shale, underlying a cement-stone. Coast, west of Billow Ness 9095

CARBONIA FABULINA, J. & K. Associated with *Cytherella extuberata*, J. & K., *C. attenuata*, J. & K., *Cytherella valida*, (?) J. & K., *Beyrichiopsis* (?) sp., *Kirkbya* (?) sp.

25. In ironstone bands, in a shale overlying a cement-stone. Coast, at the west end of Anstruther Wester 9460

CARBONIA FABULINA, J. & K., C. SUBULA, J. & K., C. RANKINIANA, J. & K. Associated with *Cytherella attenuata*, (?) J. & K.

26. In a thin band of calcareous sandstone. Coast, at the west end of Anstruther Wester . . . 9462

CARBONIA FABULINA, J. & K., C. PUNGENS, J. & K. Associated with Palæoniscid scales and teeth; *Spirorbis* sp. (large); and fragments of wood.

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27. In an ironstone band (almost formed of the remains of Ostracoda) in sandy shale. Coast, at the west end of Anstruther Wester . . . 9481

CARBONIA FABULINA, J. & K., and var., C. RANKINIANA, J. & K., C. PUNGENS, J. & K. Associated with *Cytherella extuberata*, J. & K., *C. attenuata*, J. & K., and *C.* sp.[1]

28. In shale and thin ironstones. Coast, Anstruther Wester 9720

CARBONIA FABULINA, J. & K. var., and C. RANKINIANA, J. & K. Associated with *Cytherella extuberata*, J. & K.; and the scales of *Eurynotus crenatus*, Ag.

29. In laminated, black shale, with tough bands. Coast, Anstruther Wester 9750

CARBONIA FABULINA, C. RANKINIANA. Associated with *Cytherella extuberata*; Palæoniscid scales; and the remains of a thin-shelled bivalve.

Had space allowed the filling in of full details of the strata between these horizons, showing the palæontological changes therein recorded, this account would have been much more instructive. It may, however, be explained that the whole Carboniferous series in Fife is virtually one great formation, the accumulation of which is apparently due to causes that prevailed right through, from the deposition of the lowest beds to that of the highest.

The Lower Carboniferous, or Calciferous Sandstone, is one long succession of sandstones (often false-bedded and ripple-marked), shales with or without ironstone bands or nodules, coals (generally thin) and their underclays, and thin limestones or cement-stones. Arrangements of these strata repeat themselves two or three times over in every hundred feet in some parts. In others the sandstones thicken out to fifty or one hundred feet. Or the limestones do not come in for a much greater distance, and the sandstones become broken up and interstratified with the shales, so that the section is not much unlike a bit of barren Coal-measures. In some of the shales and ironstones, and not rarely in the cement-stones, are numerous remains of plants,—not of many kinds certainly, and chiefly

[1] As an illustration of the abrupt way in which these little groups of species pass out of view for a time and allow others to come in, in the Calciferous Sandstones of Fife, it may be pointed out that, while there are no fossils in the sandy shale in which this inch band of ironstone occurs, there is, a foot or so below it, another ironstone, two inches thick, filled with an entirely different set of species, viz.—*Leperditia subrecta* (Portlock), *L.* sp., *Cytherella valida*, J. & K., *Beyrichiopsis* sp., *Spirorbis* sp., *Myalina* (?) *modioliformis*, Brown, and *Littorina Scotoburdigalensis*, Eth.

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belonging to *Lepidodendron* and two or three species of ferns. In the sandstones, or in the shales above the coals, are sometimes the stools or flattened stems of large trees,—just as in the Coal-measures, though not apparently belonging to *Sigillaria*—and macrospores are common in some of the dirty coals. The coals are never of much value. Most of them are thin, and often coarse. But they are constantly occurring; and in most cases with Stigmarian roots and rootlets in the bed below, apparently representing land-surfaces,—or something so near the surface of the waters to allow of terrestrial plant-growth.

In the lower half of this division are numerous bands of a Lamellibranch formerly supposed to belong to *Myalina*, but now referred by Dr Wheelton Hind to *Anthracomya* or *Naiadites*, a common Coal-measure genus. This shell generally occurs in great numbers; often without other mollusca, but sometimes in the same cement-stone as a species of *Schizodus* and shells of other marine genera. *Anthracosia* is also represented by one or two species, but much more sparingly, and only in the lowest beds. Besides the *Carboniæ* forming the subject of this paper, there are other Ostracoda, either marine or estuarine, that occur in great quantities in the cement-stones and darker shales, these strata being sometimes literally filled with their remains for two or three feet. The abundance of such minute fossils is a special feature in the Lower Carboniferous rocks of Fife, and more particularly in the lowest thousand feet.

Besides these animal and vegetable remains, there repeatedly appear zones of undoubted marine fossils imbedded in certain of the cement-stones, or in calcareous shales. A species of *Schizodus* is generally present in these zones in the lower portion of the division; and with it are various species of *Orthoceras*, *Nautilus*, *Bellerophon*, *Murchisonia*, *Macrocheilus*, *Loxonema*, *Naticopsis*, *Aviculopecten*, *Leda*, *Nucula*, *Sanguinolites*, *Lingula*, and other mollusca, along with a small coral (*Stenopora*), and several Ostracoda. Lamellibranchs and Gasteropods are the prevailing fossils; Brachiopods being very rare, *Lingulæ* excepted. Higher in this series Brachiopods appear in greater force in a thick bed of shale and calcareous bands. Species of *Athyris*, *Discina*, *Productus*, *Spiriferina*, and *Streptorhynchus* are found in this stratum, along with many Lamellibranchs, Gasteropods, and Cephalopods, as well as Crinoid remains. Nearly all the species are well-known Carboniferous Limestone fossils, and many of them here appear for the first time. Higher still are four other marine zones with fossils nearly all common to the Carboniferous Limestone, those peculiar to the Calciferous Sandstone having all dropped out of sight except one—*Sanguinolites Abdensis*.

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Less than one hundred feet above the highest marine zone just mentioned, and coming in in regular succession, is a limestone fully twelve feet thick (containing corals, brachiopods and other fossils), which is taken as the base of the Carboniferous Limestone Series by the Geological Survey. Above it follow about 350 feet of sandstones and shales, with five or six coals and fireclays, and three more marine limestones, as well as a thick shale full of encrinites and other fossils. The coals come in at various horizons, the highest being four feet thick and of fair quality. *Lepidodendron* and *Stigmaria* are found in the sandstones and fireclays, and macrospores in the coaly shales.

The workable coals and ironstones of the Carboniferous Limestone come on next, forming a fine series of Coal-measures, of fully more commercial importance than the true Coal-measures nearly 2000 feet above; for many of the seams are thick and of good quality. Vegetable and fish-remains, along with *Carboniæ*, are the characteristic fossils.

These are succeeded by another set of sandstones, shales, and thin coals (as well as two parrot coals of some value), that aggregate about 1000 feet in thickness. Three marine limestones and one shale are intercalated among them, the highest of the former being the Levenseat Limestone, which forms the top of the Carboniferous Limestone Series.

Seven to eight hundred feet of measures follow, representing the Millstone-grit. They are mainly siliceous, some of the thicker sandstones being coarse and gritty; but there are some shales and fireclays, as well as thin coals of no commercial value. No marine beds have been observed in this division in Fife, though such are present elsewhere.

Then come on the Coal-measures, which, including the upper red beds, are about 2500 feet in thickness. The workable coals are all in the lower portion, the lithology of which is that of ordinary coal-bearing strata. There are eight or nine thick coals, besides a number too thin or poor to work. Plants and fish-remains, mollusca belonging to *Anthracosia*, *Anthracomya*, &c.; *Spirorbis* and *Carbonia*, are, as usual, the common fossils. Forming the roof of the highest coal, and a little below the red beds, there is a shale containing species of *Discites*, *Orthoceras*, *Bellerophon*, *Murchisonia*, *Productus*, *Lingula*, and other mollusca, as well as the remains of crinoids, fishes, and plants (traces). This is the only marine zone known in this division, and thus the highest in the Carboniferous Series of Fife. The 900 feet of strata forming the top beds of the Coal-measures are highly coloured. Most of the sandstones are red, and the shales and marls of the same tint, or variegated with it and yellow and purple. Some bands of impure limestone come

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in near the centre of these beds, and with them two coals, three or four inches thick, resting on fireclays full of Stigmarian rootlets. In the roof of the uppermost coal are numerous plant-remains, as well as those of fish—*Megalichthys* and *Strepsodus*, and of crustaceans—*Eurypterus*, *Prestwichia*, and *Bellinurus*. These are the highest and last traces of Carboniferous vegetation and animal life seen in Fife.

Altogether there are nearly 120 coals—counting all sorts—in the 9000–10,000 feet of strata composing this Carboniferous series; the upper 900 feet being the portion containing the fewest.

Of marine beds twenty-five are known, and they range from near the base (as known in Fife) to within about 950 feet of the top of the series; though only one occurs in the thick mass of strata lying above the Levenseat Limestone.[1]

Through the whole of this mass of strata there are no signs of unconformity, or of anything indicating a thorough change, either in the sediments deposited, or in the manner in which they were put down,—further than changes that come into view in the first few hundred feet of the lower measures. The thin coal with its vegetable *debris* and spore-cases above and Stigmaria in the underclay below, when contrasted with the cement-stone full of marine shells, probably marks the extreme changes in physical conditions that obtained during the whole period in this area, so far at least as relates to sedimentary strata.[2] These changes occur so often, and are so continued, as to characterise the series as a whole rather than a part, and are thus of little use for divisional purposes. The division of the strata into groups is more a matter of convenience than a mark of any important difference in the lithology, or in the conditions that controlled the depositions of the masses of the strata so divided. Palæontological differences there are (as well as palæontological continuity) when far-apart strata are compared; for probably

[1] Possibly there are other marine strata in these upper measures not yet discovered in Fife, as marine mollusca are recorded from two horizons in the Millstone-grit, and from four in the Coal-measures of Lanarkshire. See Geol. Surv. of Scotland, Explan. Sheet 23, pp. 23, 91, 92; and Explan. Sheet 31, pp. 74, 75, 80. In the Edinburgh memoir of the Geological Survey of Scotland (p. 150) it is stated that *Productus semireticulatus*, *Lingula mytiloides*, and species of *Modiola Macrocheilus* and *Serpula* were found in the Millstone-grit of Fife, by Mr R. Gibbs, in 1860. No reference is made to locality.

[2] No volcanic rocks are included in this account as none are seen in the sections on which it is based, either interstratified or intrusive. So far as it goes (as before remarked, neither the lowest nor yet probably the highest Carboniferous strata are seen in Fife), the sections chosen very likely represent the sedimentary deposits of this area and period at their maximum development; the Calciferous Sandstones in the west of the county not appearing to be so thick; and the workable portion of the Coal-measures becoming thinner to the east.

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most of the plants as well as a fair proportion of the animal fossils of the lowest beds are not present in the upper. Time evidently told in its long lapse (as the Carboniferous rocks were being accumulated) among other species, if it did not with the *Carboniæ*.

It is in this thick and unbroken series of strata that species of *Carbonia* occur in the manner described, at the various horizons given in the preceding account. These occurrences have come under my own observation, and all are in Fife. But a similar association or intermixture of species evidently obtains in the Lower Carboniferous of other districts; for the following lists of Ostracoda are from material collected by the officers of the Geological Survey.

TWEEDEN BURN, ROXBURGHSHIRE.

Carbonia fabulina, J. & K.
Leperditia Okeni (Münster).
Bairdia plebeia, Reuss.
B. sp.
Cytherella sp.

LEFT BANK OF LINNHOUSE WATER, NEAR MIDCALDER, LINLITHGOWSHIRE.

Carbonia fabulina and vars.
Leperditia Scotoburdigalensis (Hibbert).
Beyrichiopsis (?) sp.
Argillœcia æqualis, J. & K.
Bythocypris cuneola, J. & K.

CRAIGKELLY QUARRY, NEAR BURNTISLAND, FIFE.

Carbonia fabulina, J. & K.
———— subula, J. & K.
Cythere superba, J. & K.
Leperditia Scotoburdigalensis (Hibbert).
L. sp.

MIDGY HOLES, No. 2, NORTHUMBERLAND.

Carbonia fabulina, J. & K.
Leperditia Scotoburdigalensis (Hibbert).
———— Okeni (Münster).
———— subrecta (Portlock).
Cytherella extuberata, J. & K.
Beyrichiopsis sp. (large).

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TABULAR LISTS OF CARBONIÆ AND ASSOCIATED OSTRACODA AS OCCURRING IN CALCIFEROUS SANDSTONE STRATA.

Loc. 12.	Loc. 17.	Loc. 27.	Loc. 23.	Linnhouse Water.	Midgy Holes.	Tweeden Burn.
1. *Carbonia fabulina*	1. *C. fabulina*	1. *C. fabulina* & *var.*	*C. fabulina*	*C. fabulina* & *vars.*	*C. fabulina*	*C. fabulina*
2. ———*Rankiniana*	2. *C. Rankiniana*	2. *C. Rankiniana*	*C. Rankiniana*			
	3. *C. pungens*	3. *C. pungens*	*C. subula*			
3. LEPERDITIA SCOTOBURDIGALENSIS[1]	4. L. SCOTOBURDIGALENSIS		L. SCOTOBURDIGALENSIS	L. SCOTOBURDIGALENSIS	L. SCOTOBURDIGALENSIS	
	5. KIRKBYA SPIRALIS				L. OKENI	L. OKENI
		4. CYTHERELLA ATTENUATA	C. ATTENUATA		L. SUBRECTA	
		5. CYTHERELLA EXTUBERATA	C. EXTUBERATA		CYTHERELLA EXTUBERATA	CYTHERELLA SP.
			CYTHERE SUPERBA			
				BEYRICHIOPSIS SP.	BEYRICHIOPSIS SP.	
				ARGILLÆCIA ÆQUALIS		BAIRDIA PLEBEIA
				BYTHOCYPRIS CUNEOLA		B. SP.

The *Carbonicæ* are printed in *italics*, the Marine Species in ROMAN TYPE.

[1] *Leperditia Scotoburdigalensis* is a degenerate form of the larger *L. Okeni*, and abounds in some black shales and limestones, formed probably in swamps and stagnant lagoons of the Carboniferous-period; and therefore to some extent it may have had a non-marine or estuarine habitat.

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It may be stated at once that there cannot be a doubt about *Carbonia* having supplied the most nearly freshwater group of species among the Ostracoda of this time. The fossils always associated with it in the Coal-measures, as well as in the Carboniferous Limestone series (*Spirorbis carbonarius* excepted), are such as may have lived in fresh water, or at least in such as was not fully salt. The fish-remains,[1] shells of the Anthracosidæ, and plants all point that way. And where marine beds do come in, in either of these divisions, *Carbonia* is not in them.

But the same cannot be said when its occurrences in the Lower Carboniferous strata are examined. For, though it is found there with similar fossils on some occasions, it is at other times associated with Ostracoda of marine habit. Reference to the preceding list will show that species of *Leperditia*, *Cytherella*, *Beyrichiopsis*, and *Kirkbya* occur repeatedly with *Carboniæ*. These are all what may be termed "marine" genera, the representatives of which in nearly every case are found along with mollusca equivalent or analogous to forms that live in existing seas. Some may have been estuarine (*Leperditia Scotoburdigalensis*, for example), and probably most of them belonged to comparatively shallow water.

The List below sums up the *Carboniæ* and Marine Ostracoda that occur together in the Lower Carboniferous strata.

Carbonia fabulina, Jones & Kirkby.
———— Rankiniana, J. & K.
———— subula, J. & K.
———— pungens, J. & K.
———— bairdioides (?), J. & K.
Leperditia Scotoburdigalensis (Hibbert).
———— Okeni (Münster).
———— subrecta (Portlock).
Cytherella extuberata, J. & K.
———— attenuata, J. & K.
———— valida (?), J. & K.
Beyrichiopsis sp.

[1] Though Fish-remains are not characteristic fossils in the Lower Carboniferous marine beds, scales and teeth of the smaller Ganoids are not of uncommon occurrence in some of the cement-stones; and now and then the larger scales of *Megalichthys* are present, but only rarely. *Rhizodus Hibberti* scarcely ever occurs in such company. I have only once seen the remains of this large sauroid near marine mollusca, and then rather just below than among them, although in the same cement-stone. But its bones, scales, and teeth are found sometimes amidst swarms of *Leperditia Scotoburdigalensis*, which in this paper is taken to be of either estuarine or marine habit. The teeth of *Strepsodus* and *Diplodus*, as well as the scales of *Rhizodopsis* and of small Ganoids, are also met with along with *Lingula*, *Murchisonia*, and *Bellerophon* in a marine shale in the Coal-measures. Possibly some of these fishes lived as well in salt water as in fresh.

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Kirkbya spiralis, J. & K.
Cythere (?), superba, J. & K.
Argillœcia æqualis, J. & K.
Bythocypris cuneola, J. & K.
Bairdia plebeia, Reuss.

For the purpose of showing the company in which these marine associates of *Carboniæ* are at other times found, and among which they are individually abundant and well developed, I add the four following lists of Ostracoda, from beds in the Calciferous Sandstones of Fife, as to the marine origin of which there can be no dispute. Those elsewhere associated with *Carboniæ* are bracketed at the top of each list.

LISTS OF OSTRACODA, SHOWING THE OCCURRENCE OF THE MARINE SPECIES OF THE PREVIOUS LISTS WITH OTHER MARINE ASSOCIATES.

Limestone No. 3a, Randerstone, Fife.

Leperditia Scotoburdigalensis (Hibbert).
Kirkbya spiralis, Jones & Kirkby.
Cytherella extuberata, J. & K.
——— attenuata, J. & K.

Associated with marine mollusca:—*Schizodus Salteri*, and *Murchisonia sp.*

Fife Coast, Billow Ness. Cement-stone and Dark Shale.

Leperditia Scotoburdigalensis (Hibbert).
Kirkbya spiralis, J. & K.
Cytherella extuberata, J. & K.
——— attenuata, J. & K.
Beyrichiopsis sp.
Beyrichia cratigera (?), Brady.

Associated with marine mollusca:—*Lingula squamiformis*, Phillips; *Schizodus Salteri*, Eth.; *Myalina* (?) *modioliformis*, Brown; and Littorina (?) Scotoburdigalensis, Eth.; and the remains of Ganoid fishes.

"*Encrinite Bed*," *Fife Coast, east of Pittenweem. Grey Shale with Calcareous and Ironstone Bands.*

Leperditia Scotoburdigalensis (Hibbert).
Cytherella attenuata (?), J. & K.
Leperditia Okeni (Münster).
Kirkbya Urei, Jones.
——— Permiana, Jones.

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Cytherella valida, J. & K.
Bairdia plebeia, Reuss.
——— Hisingeri (Münster).
——— amputata, Kirkby.
——— subelongata, J. & K.
——— brevis, J. & K.
and other species of Ostracoda.
Associated with many marine mollusca, including species of *Orthoceras*, *Bellerophon*, *Loxonema*, *Pleurotomaria*, *Aviculopecten*, *Leda*, *Nucula*, *Athyris*, *Productus*, &c., &c.; along with numerous crinoidal remains.

Limestone No. 8, *Randerstone, Fife.*

Kirkbya spiralis, J. and K.
Cytherella extuberata, J. and K.
Beyrichiopsis (?) sp.
Leperditia Okeni (Münster).
Kirkbya plicata, J. and K.
Bairdia plebeia, Reuss.
——— Hisingeri (Münster).
——— siliquoides, J. and K.
Macrocypris Jonesiana, K.
and other species of Ostracoda
Associated with marine mollusca:—*Orthoceras* sp., *Littorina* (?) *Scotoburdigalensis*, Eth.; *Macrocheilus striatulus*, Kirkby; *Murchisonia Kirkbyi*, Donald; *Myalina* (?) *modioliformis*, Brown; *Schizodus Salteri*, Eth., &c.; also Archæocidaris sp.

Hence it seems to be clear that in these Lower Carboniferous strata it is not uncommon to find *Carbonia* associated with marine types. The instances given should suffice to prove this, though others might have been added.

Of course carapaces or detached valves of *Carboniæ* (like those of existing freshwater species) may have been drifted seaward, and so mixed with marine forms of life in marine or estuarine deposits, just as vegetable remains must have been carried away from where they grew and imbedded in the same or similar deposits.[1] Some of the instances quoted of such intermixture are possibly due to this cause, for organisms so minute might easily be transported by currents. Still, I think, the association of species of *Carbonia* with marine types occurs

[1] A somewhat analogous phenomena may be recognised in the commingling of land-shells with the sands of the sea-shore, and with the foraminifera blown up from the strand, on the north and north-west coasts of Ireland, as described by Mr R. Welch in the *Irish Naturalist*, vol. vii., No. 3 (1898), pp. 77-82.

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too often to be altogether accidental.[1] As a rule they are fairly numerous when in such company, sometimes as much so as their marine associates. Their valves are also as often united as single, and altogether they quite give one the idea of being at home where they are found.

The presence of vegetable remains in a deposit may or may not indicate a freshwater origin for it. Much depends on other evidence. They certainly are common fossils in the Calciferous Sandstones in Fife,—and mainly in a fragmentary state. They occur in all kinds of strata: in the thin limestones or cement-stones, as well as in shales and fireclays; and associated with marine fossils, as well as with others of possible freshwater habitats. Broken stems encrusted with *Spirorbis* are found in the "Encrinite Bed" at Pittenweem, along with a purely marine fauna; and at Randerstone Castle a limestone, crowded with fossils belonging to *Murchisonia*, *Macrocheilus*, *Orthoceras*, &c., contains *Lepidodendron*, *Stigmaria*, and much broken-up vegetable matter. And so in several other instances plants and undoubted marine fossils are found together in the same stratum; so that the finding of vegetable remains in a Calciferous Sandstone deposit does not by any means prove that either the animal fossils associated with them belonged to fresh water, or that the deposit itself had a freshwater origin.

There can be no doubt that land of some sort, either dry or half-submerged (and probably not at all permanent) was never far off during the whole of the Lower Carboniferous period. That this land was clothed with vegetation is evident from the numerous thin coals resting on underclays containing *Stigmaria*. So that, when marine conditions prevailed over such areas as were estuarine or freshwater, it would generally be an easy matter for water-logged vegetable drift to become intermingled with the animal life on the sea-bottom.

Bearing on the question of the lacustrine character of *Carbonia*, as held by my friend Dr John Young, it may be pointed out that where its species occur in strata by themselves, or at least without the company of marine forms, they are at

[1] As a probable instance of drifted specimens it may be mentioned that among the Ostracoda from a marine cement-stone opposite Anstruther Wester are single specimens of forms not distinguishable from *Carbonia fabulina* and *C. subula*. And carapaces that look like *C. fabulina* now and then turn up in suites of marine Ostracoda from the Carboniferous Limestone series. Such specimens have been noticed by Prof. Jones and myself from Braehead, Lanarkshire; Dowgill, Yorkshire; and in a set from the Carboniferous Limestone of Soignies, Belgium. Some of these, of course, may belong to an unknown species, whose carapace simulates that of the *Carbonia* named. They all appear to be exceedingly rare.

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times in very close contiguity to beds full of marine fossils. An example of this is given in the following section of Calciferous Sandstones exposed on the coast to the west of Billow Ness. The first inch or more of the shale No. 3, immediately above the limestone, is crowded with the carapace valves of the marine Ostracod, *Beyrichiopsis fimbriata*, J. and K. The next twelve inches of shale appear to be barren of fossils. Then come one or more layers of ironstone nodules with the three species of *Carbonia* named below, along with stray fragments of the fern *Calymmatotheca affinis* (L. & H).

	Feet.	In.
1. Sandstone	6	0
2. Grey shale	6	0
3. Dark, tough shale with ironstone nodules: *Carbonia fabulina*, *C. Rankiniana*, and *C. subula* in nodules 18 inches above the limestone; and *Beyrichiopsis fimbriata* in the lowest portion of the shale	3	0
4. Grey limestone or cement-stone: full of marine fossils, such as *Bellerophon decussatus*, *Murchisonia striatula*, *Leda attenuata*, *Sanguinolites Abdensis*, *Leperditia Okeni*, *Beyrichiopsis fimbriata*, &c.	1	0
5. Black shale. Palæoniscid scales and plant-remains	0	8
6. Coal	0	3
7. Fireclay. Stigmarian roots and rootlets . .	2	6
8. Purple-grey shale, with large flattened stems .	2	6
9. Sandstone	8	0

Another example of this stratigraphical juxtaposition of *Carbonia* to marine beds occurs near the top of the Carboniferous Limestone series on the coast between Dysart and Ravenscraig Castle. *Carbonia fabulina* (associated with *Calamites* sp.) is there found in the ironstone bands of a grey shale, separated by 6 feet of sandstone from the marine shale lying below the Levenseat Limestone. These latter strata—the limestone with the shales below and above it—are over 20 feet in thickness, and contain many species of marine mollusca belonging to *Orthoceras*, *Goniatites*, *Pleurotomaria*, *Spiriferina*, and other genera.

Dr John Young, of Glasgow, in a letter, remarks that it may be interesting to point out one series of the changes from "freshwater" to "marine" strata that have taken place during the deposition of the Lower Limestones of the Campsie district; such as are known from old workings and from the details of

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borings. He gives the following list of beds, in descending order, observed in one of the bores.

	Fath.	Ft.
1. Bluish grey shales. *Marine*	22	2
2. Campsie Main Limestone. *Marine*	0	4 to 6
3. Alum shale. *Marine*	0	2 to 4
4. Campsie Main Coal. *Land-growth*	0	4 to 5
5. Under- or fire-clay. *With Stigmaria*	0	1 to 3
6. White limestone. *Lacustrine; Carbonia* and *Spirorbis*	0	4 to 5

These show, at Campsie, that changes from lacustrine and terrestrial to marine took place during the formation of about 12 feet of strata, of thin-bedded sandstone, coal, fire-clay and limestones (lacustrine and marine).

The lowest of these (6) begins with a lake deposit, with *Carbonia*, *Spirorbis*, and some Ganoid Fishes.

(5) Indicates the lake becoming a land-surface.

(4) Growth of coal-forest, known to extend over a wide district.

(3) A rich alum-shale, with fossils marine and brackish.

(2) A richly organic marine (deep-sea) limestone.

(1) Shales, marine, indicating shallower and muddy seas.

A very clear instance of the same thing has lately been given by Mr J. Smith, of Kilwinning, in the *Geological Magazine* of November last. He there publishes a section of Lower Carboniferous Limestone strata to show the position of a bed of freshwater Ostracoda, discovered by him in the Gurdy cutting of the railway from Giffen to Kilbirnie. The section is given below, and Mr Smith having favoured T. R. Jones and myself with a series of the Ostracoda, the names of the species are here given.

	Ft.	In.
1. Highest marine limestone seen in the cutting	...	
2. Black shale, tough	1	8
3. Dark shale	0	8
4. Dark shale, crowded with "freshwater" Ostracoda: *Carbonia fabulina* and varieties, *C. Rankiniana* and variety, *C. secans*, *C. pungens*, and *Beyrichia arcuata* [1] (Bean)	0	9
5. Dark shale	1	6
6. Sandstone with *Stigmaria*	3	6
7. Thick bed of dark shale with an abundance of marine fossils	...	
8. Limestone with marine fossils	...	

[1] A common species in the Coal-measures.

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It will be observed that the shale No. 4, which is full of *Carboniæ*, is only 5 feet above one marine horizon, and rather more than 2 feet below another marine horizon.

Such instances as the preceding could easily be added to,—from the Calciferous Sandstones certainly, and I dare say from the Carboniferous Limestone Series as well. They do not, of course, prove that the conditions were exactly the same when the marine beds and those containing the *Carboniæ* were deposited. The sea may have spread over the area in the one case, and brackish or fresh water in the other,—and most likely did. But they certainly show that such freshwater conditions could not have been lacustrine, and due to such as would prevail in an isolated or inland lake-basin; but rather what we might expect to find where great rivers discharged into the sea, spreading their sediments in the form of deltas, with their probably brackish lagoons, over wide areas of a nearly constantly subsiding bottom.

By looking at the subject in this light, it is more easy to understand the presence of limestones and shales containing marine fossils lying so near to shales and ironstones whose only fossils are *Carboniæ* and plants; as well as the intermixture of *Carboniæ* with Ostracoda that at other times are found associated with marine Mollusca. For in such areas there would be the river with freshwater forms of life and conditions on the one hand, and the sea with marine forms of life and conditions on the other. In times of flood, or when subsidence was slight (or wanting), the former would advance seaward; but at other times, when depression exceeded the deposition of sediment, marine conditions and life would extend landward and overlap the sand, mud, and silt with the vegetable and animal remains that the river (or rivers) had previously put down. This indeed seems to be the only way in which to account for so great an accumulation of shallow-water deposits and coal-growths, along with the continued repetition of strata containing marine fossils.

So far, then, as I can read the evidence, the *Carboniæ* in the earlier days of their history often lived in the rivers, or in the quiet backwaters, lagoons, and swamps of the river-deltas of the Lower Carboniferous period as fluviatile Ostracoda. At other times they lived in brackish or salt water, in company with estuarine and marine types of the same tribe,—just as certain recent *Cypridæ* associate with species of *Cythere* and other marine genera in the estuaries, and in the pools of the salt marshes of Northumberland and Durham, and other districts at the present time.[1] In the later portion of their

[1] See Dr G. S. Brady in Trans. Nat. Hist. Northumb. and Durham, vol. iii., 1868; and *Ann. Mag. Nat. Hist.*, July 1870.

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history, in the Coal-measure time, they possibly did not range out of fresh waters, as none of them are known to accompany the fossils of the marine zones of that formation. They may thus be, notwithstanding their earlier latitudinarianism as to habitat, very likely about the earliest forerunners known of the present-day *Cyprides*.

Of course in all that has been said, I have, for my part, been referring mainly to what is seen in the Carboniferous rocks of Fife, and scarcely at all as to what is to be observed in the same rocks in the West of Scotland. Though it seems reasonable to assume that, if *Carbonia* was not *lacustrine* in the one district, it is scarcely likely to have been so in the other.

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LV.—*The Felspars Present in Sedimentary Rocks as Indicators of the Conditions of Contemporaneous Climate.* By Wm. Mackie, M.A., M.D. (Plate XXVI.)

(Read 7th April 1898.)

In February of last year, in a paper read before the Literary Institute, Nairn, I called attention to variations in the state of preservation of the felspar fragments included in the sandstones of the Old Red and Reptiliferous rocks of the Elgin area, and suggested as a possible explanation of the differences observed, variations in the conditions of climate in the periods represented by the different beds. Since then I have gone a little more fully into the subject, and am now in a position to examine somewhat more critically the thesis that—*the conditions of the felspars present in sedimentary rocks may yield important evidence regarding the climatic conditions that prevailed during the period of their deposition;* and, further, to indicate briefly, on the strength of more determinate results, the particular conditions that appear to have obtained during such of the geological periods as are represented in the north of Scotland by unaltered sedimentary deposits.

Variations of the felspars observed in the sedimentary rocks of Moray.

Little, apparently, has been done in this line of research, though the question raised cannot be said to be exactly new. As early as 1879 the officers of the Geological Survey of India[1] had noted the occurrence of undecomposed felspars in the Talchir and Panchet beds of that country. In the case of the former, from the nature of the associated deposits they inferred the operation of ground-ice on the land-surface of the period represented by these rocks. Since then they appear to have come to the conclusion, on the strength of the undecomposed felspars alone, that the recurrence of a cold spell is also indicated during the deposition of the latter beds. In 1896, G. P. Merill,[2] as shown by a paper contributed to the Geological Society of America, had independently arrived at similar results from a survey of some of the sedimentary rocks of New England; while Professor Judd, in a report on the deposits of the Nile delta,[3] communicated to the Royal Society in 1885, had specified

Literature.

[1] "Manual of the Geology of India," pp. 112, 132. Medlicott & Blandford, 1879.

[2] I have not been able to consult this paper. "Bulletin Geo. Society of America," vol. vii. p. 362.

[3] "Proceedings of Royal Society," vol. xxxix. p. 213.

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some of the principles involved when he attributed the remarkable freshness of the felspar fragments therein contained to the particular form of rock-disintegration that takes place under the influence of a torrid and practically rainless climate. These, with the addition of the observations made by the author in the unpublished paper above referred to, comprise, so far as I am aware, the total literature of the subject.

Principles.

For the purposes of this inquiry rock-disintegrating agencies are considered as falling into two classes: (1) those which act *Mechanically*; (2) those which act *Chemically*. The mechanical group of agencies do their work simply by splitting up, grinding down, or otherwise pulverising the solid rocks, without effecting material change in the resulting debris. The chemical agencies, on the other hand, act by changing the chemical character of some or all of the rock-forming minerals, and generally by softening, or, it may be, by partially dissolving them, so facilitate the disintegration of the rock masses. In the mechanical group are included the grinding action of land-ice, the chiselling effects of frost, the disruption of the rock particles produced in the absence of moisture, purely by the effects of expansion and contraction under extremes of temperature. These agencies break up the rocks, but effect no change in the chemical character of their constituent minerals. The felspars are broken up, may in fact be reduced to the very finest powder, but remain essentially fragments of felspar still. Under the chemical agencies are included the action of atmospheric moisture, of oxygen, of carbonic acid, and perhaps, in some degree, of the acids resulting from vegetable decomposition. Under their influence felspar is ultimately converted into kaolin, soluble carbonates of the alkalies and alkaline earths, and free silica, but long before they reach that stage of final disintegration, under the influence of these agencies, the felspar fragments take on a dull, opaque, lustreless, limy appearance, accompanied in the case of coloured varieties also by loss of colour. They in fact undergo the change which is generally known as *Kaolinisation*.

Rock-disintegrating agencies of two kinds—*Mechanical* and *Chemical*.

From this it will be seen that wherever we find fresh felspars in a sediment, we have indicated the operation of the mechanical rock-disintegrating agencies—the operation of glacier-ice, of keen frost, or, it may be, of extreme heat, as well as cold in the absence of moisture. Hence in such case we infer the existence during the deposition of such sediment of either

Fresh felspars indicate the operation of the mechanical agencies.

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a very cold or a very warm and dry climate. Where, on the other hand, kaolinised felspars are present in abundance, we have indicated the operation of the chemical agencies, of atmospheric moisture, of oxygen and carbonic acid, and generally it may be inferred all the conditions implied in a temperate and humid climate.

Kaolinised-action of chemical agencies.

The following examples are taken from recent deposits, where the conditions in operation are presumably better known :—

(1) A specimen of a boulder clay, derived, as far as could be judged, directly from crystalline rocks containing abundant felspars, was found to show 86% of its contained felspar fragments in a state of remarkable freshness, the remaining 14% as more or less kaolinised. Here we have a sample of rock debris which has been undoubtedly produced by mechanical agency under conditions which were as undoubtedly glacial, and the result is a preponderance of fresh felspars.

Examples : (1) A boulder clay.

(2) A sample of sand from the river Spey, near its mouth, showed 81% of kaolinised, the rest as fresh, or moderately fresh felspars. Here we have an aggregate of particles which have been exposed for longer or shorter periods to the action of a temperate and moist climate, and the result is a preponderance of kaolinised felspars.

(2) Sand from River Spey.

(3) Profr. Judd found in the deposits of the Nile delta a large proportion of remarkably fresh felspars. These existed generally as well-rounded particles, showing that over large distances they had probably been conveyed by wind, and owed their freshness, it was believed, to the peculiar action of the hot and practically rainless climate of North Eastern Africa.

(3) Nile delta deposits (Profr. Judd).

These so far are the general principles involved in the question at issue, but many other considerations have to be taken into account before an authoritative opinion can be given regarding the climate that prevailed during a particular period from an inspection of the felspars included in the sediments of that period. We cannot from the mere presence of kaolinised felspars determine with absolute certainty the existence during the period indicated of a moist and temperate climate, while, as we have just seen, the presence of fresh felspars is by itself equivocal as between extreme heat and extreme cold. But it

Inferences from the condition of felspars not absolute.

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Character of Sediments generally has to be considered.

will usually be found that in the general character of the associated sediments there is sufficient evidence to guide us to a reliable conclusion. In the case of fresh felspars, for instance, we have to decide whether they owe their presence to a torrid or frigid climate. If frigid, we expect to find side by side with the fresh felspars evidence of the existence of land-ice in the presence of large and angular blocks of rock arranged irregularly in the beds, in the evidence of rapid and torrential rivers from periodical melting of snow, in beds of conglomerate, in the general angularity of the finer particles which compose the strata, and, it may be (though this, so far as the present inquiry is concerned, is discounted) in the absence, scarcity, or peculiarities of the representative faunæ or floræ. Torrid conditions, on the other hand, would be indicated by fine sediments, and as in the absence of moisture wind would naturally be the chief agent of transport, the constituent particles would for that reason be expected to be more or less rounded. Fine sediments showing angular particles and a preponderance of fresh felspars might be attributed to carriage by low rivers under the influence of a warm, dry, and calm climate.

Initial conditions of the felspars in the crystalline rocks.

Again, in this inquiry it is important to determine, where possible, what was the initial condition of the felspars in the crystalline rocks from which they were derived. The case of fresh felspars is here a simple one. If found fresh in the sediments under examination they must have existed as fresh felspars in their native rocks. When on the other hand they are kaolinised, the following questions will naturally occur. Did they exist as fresh felspars in the parent rocks? and have the changes observed *wholly* taken place as the result of external climatic conditions, or were they altered to some extent before leaving the parent rock, and if so, how much of the aggregate change is initial, how much due to later changes? The felspars of many crystalline rocks, as is well known, show, as they exist in their native rocks, a considerable amount of alteration. Thus some specimens of Peterhead granite show the felspars so highly kaolinised that they remain practically opaque in very thin sections, and the same remark applies to a proportion of the felspars of a grey Swedish granite largely used for monumental purposes, which I had lately occasion to examine. Of the local granites, the debris of several of which is known to enter largely into the composition of some of the sediments which have been examined in this connection, the Benrinnes rock shows

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felspars which have undergone some degree of alteration, while in the others, with the exception of some of the plagioclases in Ardclach, Kinsteary and Abriachan granites, they are generally very fresh. The presence of kaolinised felspars in a sediment, therefore, need not always indicate that they have been subjected to the influence of a temperate and humid climate. It is desirable in such cases to ascertain, where possible, the origin of the felspars, and to compare the specimens in the sediments with those in the original rock. This in the majority of instances it will be impossible to do. But the difficulty arising from this source may be largely eliminated by comparing the results of determinations from a number of widely separated points in the same formation, where it is to be presumed the felspars have been derived from different series of rocks. Only where isolated determinations are considered need initial differences in the condition of the felspars give rise to any difficulty. Further, it is not unlikely that, even in the same mass of rock, variations in the conditions of the felspars as to weathering occur from time to time, as denudation proceeds purely as the result of external climatic conditions. At the present day all granites on exposed surfaces and for a varying depth into their mass, show the same changes as take place on exposure to a moist and temperate atmosphere, but the depth is generally greater in rocks that were not subjected to glaciation during the ice-age. A granitic area furnishing kaolinised felspars to the sediments now in progress would, after a period of glaciation, which would carry away all the decomposing rock rind, eventually yield fresh felspars to sediments then in progress or immediately afterwards to be formed. From this consideration, then, it is reasonable to suppose that the initial condition of the felspars in the crystalline rocks may after all not be of such importance as at first sight would appear, that, in fact, it is possible, if not highly probable, that correlative changes take place in both from the operation of the same external causes.

Condition of felspars in local granites.

Possible correlative changes in felspars of original rock masses, with variations of external climate.

Again, as is well known, the susceptibility of the different felspar species to the action of weathering influences is very different. Plagioclase felspars as a class decompose much more readily than either orthoclase or microcline. Their susceptibility as a class is apparently in direct proportion to the amount of lime they contain, while the accompanying analyses of some of the sandstones of the area would appear to indicate

Different susceptibilities of different felspar species to chemical change.

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that soda felspars may be more readily attacked than potash felspars.

ANALYSES OF SANDSTONES.

	L.O.R. Foyers.		L.O.R. Fochabers.	
SiO_2	73·32		59·24	
Al_2O_3	11·31		6·65	
Fe_2O_3	3·54		2·02	
FeO	0·72		0·31	
MnO_2	Trace		0·50	
CaO	1·35		16·04	
MgO	0·24		0·12	
K_2O	6·16	8·5 per cent.	2·30	2·49
Na_2O	2·34		0·19	
CO_2	0·92		12·16	
H_2O	0·30		1·26	
	100·20		100·79	

CHEMICAL ANALYSES OF NEWTON SANDSTONE AND ROSEBRAE SANDSTONE.

		Newton.			Rosebrae.	
SiO_2		85·68			92·13	
Al_2O_3		10·76			4·42	
Fe_2O_3		·52			·37	
FeO		·23			·33	
MnO_2		Minute trace			·24	
CaO		1·00			1·27	
MgO		Trace			·14	
K_2O		1·57	1·69		·72	·83
Na_2O		·12			·11	
Loss on ignition	H_2O	·43	·50	H_2O	·42	·42
	CO_2	·07		CO_2	None	
Sulphuric acid		Trace			...	
Chlorides		Traces			...	
		100·26			100·15	

Microcline, as has been repeatedly observed during this investigation, is particularly resistant, and even in sediments where the bulk of the felspars has undergone kaolinisation to a degree, the fragments of microcline show a freshness which is often quite surprising. Ordinary orthoclase occupies an intermediate position between microcline and plagioclase in relation to susceptibility to weathering; but

Plagioclases most susceptible; microcline least.

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different varieties of orthoclase exhibit different degrees of resistance to change. Some weather very readily, others are attacked with difficulty, and one of the impressions left on my mind by this research is that red orthoclases as a class are decidedly more resistant than white. Among the former the red orthoclase of the Torridon Sandstone, derived from the Archæan gneiss, may be cited as a conspicuous example. Again, of the fragments of granite found in the L.O.R. conglomerates of Eastern Moray the red varieties still possess some degree of cohesion, while the fragments of grey granite in the same beds crumble to a half-gritty, half-soapy powder on the slightest pressure. Large crystals of orthoclase again are found to be more resistant than small, but this is probably only an illustration of the chemical law that increasing fineness of mechanical division proportionately facilitates chemical action. Similar differences no doubt occur among the varieties of plagioclase felspar. On the whole, however, though in a critical examination the point has to be steadily kept in mind, any difficulty that such differences present is likely to be eliminated when a large number of results is considered. On the other hand, the differences of the various felspar species in respect of susceptibility to change may occasionally be made the basis of even more precise deductions than could possibly be made from a simple survey of the felspars as a whole. Thus, if plagioclase felspars appear in any sediment in as fresh a condition as they do in their native rock—and this they do in particular in the sandstones and overlying conglomerates of Mealfourvornie—we know at once that the conditions of climate under which these beds were deposited were very different from those that obtain at the present day. In the L.O.R. plagioclase felspars are of relatively frequent occurrence. They are less frequent in the U.O.R.. The felspars of the Netherly diorite—plagioclase of course—are characteristed by the presence in them of inclusions of innumerable rods and hexagons of the oxides of iron and titanum often arranged in lines along the cleavage planes of the mineral in what is known as schiller structure, but as often found radiating irregularly through the crystals in all directions. In the L.O.R. red rocks, in which the waste of the diorite has been detected, though not in abundance, I have observed fragments of this plagioclase exhibiting the arrangement of inclusions just described, and this at a distance of fourteen miles from the parent rock. The characteristic quartz grains of the same rock are present in considerable numbers at Scaat Craig in the U.O.R. series, but there the associated plagioclases are conspicuous by their absence. Plagio-

Different susceptibilities of felspar species the basis of more precise deductions.

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clases are rare in this division of the U.O.R. beds. Such as occur are so decomposed that they are recognised as plagioclases only by their exhibiting faint traces of parallel striation, and are never found to show the polariscopic effects characteristic of fresh plagioclase. Thus, within a distance of five miles of their origin, the felspars of the Netherly diorite have, under the conditions of climate then obtaining, been to all intents and purposes practically eliminated. Such observations confirm in a remarkable manner the deduction derived from an examination of the felspars generally, that wide differences of climate existed between L.O.R. and early U.O.R. times. Again, where the conditions have been such as to eliminate the more susceptible felspars, there is a tendency to accumulation—as shown by a relatively high percentage—of the more resistant felspars in the resulting sediments. Thus one analysis of the Cuttieshillock sandstone gave 79 per cent. orthoclase and unrecognisable felspars and 21 per cent. of microcline. Plagioclase has been noted from this locality, but is infrequent, and almost always all but unrecognisable.

From the variability of the felspar species as regards susceptibility to weathering, the following emerge as general propositions:—

1. Where easily recognisable plagioclase felspars are abundant, it may be safely concluded that the operation of the mechanical predominated over the purely chemical agents of disintegration.

2. The absence of recognisable plagioclases where the presence of rock debris known to be associated with them in the parent rock would naturally suggest their presence also, points no less conclusively to the operation of the chemical agencies.

3. Where the more resistant felspars, such as microcline, appear to be in excess of what might reasonably be expected from a survey of the rocks that have gone to make up the sediments in question, the operation of agencies calculated to eliminate the less resistant may be reasonably inferred.

Another point which requires to be considered before a final decision can be arrived at in a given case is how far subsequent changes in the sediments may have affected the character of the included felspars. It will be evident that where fresh felspars are now found in the sedimentary rocks, they must have entered them in that condition. Only in the case of a certain degree of metamorphism of the sediments could it possibly be expected that once kaolinised felspar could again be restored to freshness, but as that case is

Subsequent changes in sediments, and how far they may have affected the felspars.

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beyond the scope of the present paper, it need not be considered now. The converse case of kaolinised felspars is, however, fraught with some difficulty. In the case of open-textured sandstones or conglomerates, the percolating water might easily convert originally fresh felspars into highly kaolinised. And this, I believe, has actually taken place in some of the rocks presently to be considered: in some of the L.O.R. conglomerates of Eastern Moray, notably at Gollachy Mill, where fragments of felspar, particularly of white orthoclase, are to be found bounded by regular cleavage planes, but so soft as to go down to a fine soapy powder on pressure between the finger and thumb. These are associated with fragments of the same felspar, showing an exceptional degree of freshness, and the inference is that the former have undergone this change, since they were included in the conglomerate beds. The test of original freshness lies in their angularity of outline. Fragments of such softness would have quickly taken on a degree of rounding under the influence of the surface agencies—if indeed they were calculated to survive their operation for ever so short a time. At Cardenhills, again, in the U.O.R. division, where the felspars are usually very fresh, more or less kaolinised felspars have been seen along the edges of the joints—that is, in positions where the meteoric waters would naturally find readiest access.

Again, some of the substances usually associated with the felspars in ordinary sandstones might be expected in some instances to produce chemical change in the latter. In many of the L.O.R. beds, the quartz grains exhibit marked corrosion of their surfaces. It cannot therefore be expected that the less resistant felspars have escaped intact. But their freshness is certainly very remarkable in many sandstones where a certain amount of oxidation and hydration has evidently gone on, as shown by the presence in quantity of the hydrated peroxide of iron. But it is very evident, I think, that the oxidation and hydration of iron ores has taken place under conditions that have had little or no effect on the felspars. The hydrated oxides so formed apparently exert no action beyond occasional infiltration of the cleavage planes of the felspars with which they are associated. Indeed, I am of opinion that their presence, as well as that of carbonate of lime, is rather preservative of the felspars than otherwise. In some cases, however, where subsequently to deposition water containing iron in solution has infiltrated the beds, the hydrate has been deposited in relatively greater quantity around decomposing felspars than around the quartz grains and fresh felspars. This must not be confounded with chemical action on originally fresh felspars, and it has also to be distinguished from the

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deposition of the hydrates on the various grains *pari passu* with the accumulation of the sediments.

Another point which must occasionally be taken into consideration is the possibility of the derivation of felspar fragments from previously existing sediments, and how far the conditions of such felspars may be relied on to yield authoritative evidence regarding contemporaneous climate. If a proportion of the felspars are known to be derived from previously existing sandstones, the evidence is to that extent weakened, unless their condition as they existed in these earlier sediments is known. The following general cases may be put :—

Derivation of felspars from previously existing sediments.

1. If the felspars are *fresh in both* sediments, we would infer a continuance of like conditions, or at least the operation in both cases of the purely mechanical rock-disintegrating agencies. In some cases, however, the transference has apparently been effected too quickly to admit of the climatic conditions then prevailing to have effected a change.

2. If *fresh in first* and *kaolinised in second*, we would naturally infer a *change of conditions* in the interval.

3. If *kaolinised in both, no inference is warranted.*

The following are given as examples :—

Fresh felspars characterise our present boulder clays. In more recent sands, generally, kaolinised felspars predominate, but in some a proportion of fresh felspars occurs, some of which have no doubt been derived directly from the boulder clays. The inference is that they have been transferred from the one set of deposits to the other too quickly to allow the present climatic conditions to exert their influence. Again, the Reptiliferous sandstones of Cuttieshillock have been derived in large proportion from the U.O.R. rocks to the west of their position. The latter set of beds contain a large proportion of fresh felspars, but these have mostly been kaolinised in the transference to the Reptiliferous rocks. The inference is that the climate changed in the interval. Further, in almost all the boulder clays of the Moray area a proportion of kaolinised felspars occurs. As they are associated in these deposits with a proportion of finely rounded, iron-stained or secondary quartz-encrusted grains, it is inferred that they have been derived to that extent from the sandstones of the area, and along with them has no doubt gone a proportionate number of felspar fragments. As the latter were already probably kaolinised before they left the sandstones, they give no indication of the intervening climate.

Examples.

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Another question which will naturally be asked is: How closely may changes in the condition of climate be expected to be followed by corresponding changes in the characters of the felspars? There may, to be sure, be considerable mixing of results during transitional periods, as the following *hypothetical* case will show. If a period of glaciation were to immediately succeed the present condition of things, the sediments formed then and for some time thereafter would be expected to show a high percentage of kaolinised felspars, from the grinding down of the rock-rind which has undergone change under the present climatic conditions; but eventually when that had been completely ground away, fresh felspars would come to characterise the sediments then being formed. If such change took place gradually, we should expect the results as regards the felspars to be correspondingly delayed; so that we may fairly conclude that a considerable interval may separate the operation of a particular set of climatic conditions, and the appearance of the particular kind of felspars by which it is characterised. As already stated, many of the fresh felspars in sediments of the present day were probably separated from their parent rocks during the glacial period, by the operation of agencies that characterised that time; but they continue to affect the facies of the felspars in the sediments being formed now. Hence the influence of one set of climatic conditions may continue to affect the sediments formed long after they have passed away. Rightly considered, however, the last case is really an example of derivation from earlier sediments.

Closeness of sequence between changes of climate and appearance of corresponding felspars.

That differences exist in the condition of the felspars in sedimentary rocks will readily be admitted, but as to the cause of such differences, opinions may be expected to vary. Other causes may be suggested. If we tabulate in parallel columns the character of the grains of the several deposits as regards roundness or angularity, and the condition of the felspars as regards weathering in the same deposits, it will be found that kaolinised felspars are generally though not invariably associated with rounded grains, while fresh felspars are as frequently associated with angular grains. This at first sight would seem to imply that it is simply a question of the length of time the various sediments have been exposed to the influence of the atmospheric agencies, which may, hypothetically, be supposed to be practically constant in their action; or otherwise, that it is the rate of sedimentation that is the cause of the observed differences.

Possibility of other causes for variations of felspars.

Kaolinised felspars associated with rounded grains.

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If we take the degree of rounding of the particles as the natural index of the length of time they have been exposed, we should of course expect that the degree of alteration of the felspars and the degree of rounding of the grains should vary together. This, however, they do not do. Two exceptions may be given by way of examples. The sand of the river Spey may be described as typically angular, yet 81 per cent. of the felspars of this sand are kaolinised. The particles of the L.O.R. from Dipple or Gollachy Mill, which I have shown elsewhere to be more rounded than the particles of the sand of the Spey, show 70 per cent. of fresh felspars. Again, in the same paper, the particles of the U.O.R. of the Rosebrae division of the U.O.R. rocks of Elgin are shown to be more rounded—and they are also finer—than the present sea sand of the Moray coast, yet the former show 60 per cent. of kaolinised felspars, the latter 72 per cent. As regards the felspars in recent sands, it is certainly not a question of the length of time they have been in transit from their parent rocks to their present position. The process of kaolinisation is well advanced, if not nearly completed, before they leave these rocks, and, on the hypothesis that it is simply a question of the length of exposure to an atmosphere practically uniform in its action, one wonders how from a kaolinised rock-rind the presence of fresh felspars in sediments is to be explained at all.

Test of Kaolinised Felspars.

Before going on to consider the results obtained from examination of the various sediments, it will be necessary first of all to go into the question of tests of kaolinised in contradistinction to fresh felspars, and to indicate in a general way the methods that have been followed in obtaining the tabulated results.

Where the felspar fragments are of some size, so that their characters are evident to the naked eye, the fresh, lustrous, cleavage planes of the fresh felspars, as against the dull heavy surfaces of the kaolinised mineral, will be quite sufficient for the purposes of diagnosis. Accordingly, where possible, I have secured large specimens of felspar fragments from the various sediments, and these are now exhibited as card specimens with localities marked. From these it will be seen that in the L.O.R. of eastern Moray, but at some distance above the base, both white and red felspars occur, presenting a degree of freshness that is simply wonderful. From Scaat Craig in the U.O.R. there are specimens, one of them a small fragment of graphic granite, which indicate some degree of alteration. From Newton, in the same series, we have red felspars which are as fresh as we might

Naked eye determinations in case of large fragments.

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expect to find them in their native rock. A fragment of graphic granite from this locality shows less alteration than a specimen taken direct from one of the pegmatite veins on the Rothes Burn, from some of which the Newton fragment was probably originally derived. Another is seen from Cardenhill, in the same division of the U.O.R., showing some degree of alteration, but that has probably taken place since its inclusion in the rock, as such changes have been observed in the felspar fragments here. The large fragments of felspar from Newton, though some of them have evidently been rolled, show no external zone of alteration such as is seen in rolled fragments at the present day. In the L.O.R. to the west, in many places, notably near Foyers, we find the felspars in the basal beds as fresh as they now are in the Stratheric granites, to which they are in large part traceable.

Again, as kaolinisation means hydration, the giving off of water on strongly heating is a certain test of the change. From the following chemical formulæ, which represents the change of orthoclase felspar into kaolin on exposure to the atmospheric agencies, it will be seen that the quantity of water given off is a measure of the amount of orthoclase so changed:—

$$\underbrace{Al_2O_3\ K_2O\ Na_2O\ 6SiO_2}_{\text{Orthoclase}} + \underbrace{2H_2O + 2CO_2}_{\text{Atmosphere}} =$$

$$\underbrace{Al_2O_3\ 2SiO_2\ 2H_2O}_{\text{Kaolin}} + 4SiO_2 + K_2\,CO_3 + Na_2\,CO_3$$

and kaolin ($Al_2O_3\ 2SiO_2\ 2H_2O$) heated gives off $2H_2O$; that is to say, 258 parts of kaolin give off 36 parts by weight of water. A sample of kaolin washed from a fragment of decomposing red granite in the L.O.R. of Scaat Craig gave, after being air-dried, 8·29 per cent. of water, which without further analysis would go to show that it contained 59·3 per cent. of true kaolin, with a balance of 40·7 per cent. of free silica. *Expt.: A fragment of kaolinised felspar—from the summit of Cairngorm—heated in a small bulb-tube is seen to give off water which condenses in tiny drops round the neck of the tube.* So intimately is the process of hydration associated with the chemical decomposition of many minerals, that it may be taken as a very good all-round test of such change, and the amount of loss on ignition, subject to certain corrections which may be specified, may be taken as a fair measure of its amount. A few determinations of the water of hydration of several of the sandstones, and of other rocks for comparison, are given in the accompanying table.

Amount of water of hydration suggested as measure of chemical change.

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Table of Relative Hydrations of Sandstone.

I. Beds.	II. Total Loss on Ignition.	III. Carbonic Acid.	IV. Water.	V. Peroxide of Iron.	VI. Relative percentage of Felspar Particles.	VII. Relative Hydration per Felspar Unit	VIII. Comparative Numbers.	IX. Remarks.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.			
Torridon . . L.O.R.	·83	·19	·64	Not estimated.	55	·012	12	[1] Interstitial Iron only. [2] Structural and Interstitial Iron.
Foyers . . .	1·22	·92	·30	,,	60	·005	5	
Fochabers . .	13·42	12·16	1·26	1·3[1]	30	·035	35	
Tynet . . .	15·55	13·15	2·40	2·17[1]	38	·054	54	
Tarradale . . U.O.R.	5·25	2·75	2·50	1·41[2]	35	·065	65	Contained 6·25 per c. of $CaCO_3$. See full analysis in Appendix.
Scaat Craig . .	19·66	17·93	1·73	1·89[2]	17	·083	83	Contained 40·75 per. cent. of $CaCO_3$ and 1·7 lime as silicate.
King Steps . .	3·84	2·75	1·09	·70[2]	18	·054	54	Contained 6·25 per cent. of $CaCO_3$ and ·75 lime as silicate.
(Other specimens)	...	..	...	...	40	·024	24	
Newton . . .	·5	·07	·43	·52[2]	16	·026	26	
Rosebrae . .	·42	None.	·42	·37[2]	12	·030	30	
Bishopmill . .	·74	·12	·62	·46[2]	16	·035	35	
Dura Den . . *Reptiliferous.*	8·16	6·37	1·79	·43[1]	9	·195	195	Contained 1·4 per cent. of FeO, probably as $FeCO_3$.
Cuttieshillock . .	·65	·12	·53	·63[2]	7	·061	61	
Findrassie . .	4·72	2·64	2·08	·33[1]	12	·169	169	
Covesea . . .	1·85	·22	1·63	Not estimated.	6	·270	270	
Spynie . . . GRANITES.	·50	·35	·15	·24[1]	15	·007	7	
Rubislaw granite .	1·36	...	...	...	...	...	...	
Grey Swedish granite	1·23	...	...	...	...	...	...	
Dark Russian granite	·58	...	...	...	...	...	...	
Benrinnes Red .	·34	...	...	...	...	...	...	
,, Grey .	·75	...	...	...	...	...	...	

One-sixth the value of the amount of iron peroxide present has been deducted from the values in Column IV. as the amount of water associated with the tide. The remainder has then been divided by the numbers in Column VI., thus giving the numbers in Column VII. The numbers in Column VI. are only approximate, as the determinations have been made on different specimens from those examined for hydrain. In the case of the Tynet and Fochabers specimens the number of schist particles present have been counted along with the felspars. The results obtained so far agree with those obtained from the felspar determinations, though one or two notable exceptions occur.

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In some cases they accord fairly well with the corresponding felspar determinations. In other cases they do not apparently do so. It should be remembered, however, in this connection, that the amount of felspar present is itself a variable quantity. We cannot, therefore, but expect that a rock which shows 40 per cent. of felspar fragments will, *cæteris paribus*, show a relatively greater quantity of water of hydration than one which shows only 6 per cent. Corrections, it should be noted, have to be made for the hydrated oxides of iron, for sulphate of lime, when present as a cement, and also for carbonic acid, if the quantity of water of hydration is to be estimated by simple loss on ignition. Other determinations bearing on these points are in progress. Those in the accompanying table are all that have been made up to the present time.

Local peculiarity in kaolinised felspars at King Steps.

A local peculiarity observed in kaolinised felspars, which, as it suggested a possible chemical test of that condition, deserves a passing notice, was found to obtain in the case of certain sandstone bands in King Steps Quarry near Nairn. Here the rock, which generally shows carbonate of lime as a cement, was found to be impregnated with sulphide of copper. Now in this zone the kaolinised felspars were found to be all stained more or less of a fine copper colour, evidently from some process of reduction of the copper sulphide to the metallic state, but the reaction is certainly one which is difficult to trace by chemical equation. Attempts at imitation by placing kaolin and kaolinised felspars in contact with copper sulphate in solution appeared to give slight positive results, and the effect was intensified by subsequently alkalinising with carbonate of soda; but altogether the results were too meagre to give any hope of the process proving useful as a test of kaolinisation—at least within a reasonable time.

Methods of Work.

For rapid microscopical work, the mere observation of the characters of the various felspar fragments in simple transmitted, or transmitted aided occasionally by reflected light, is likely enough to give results which will be sufficiently accurate for comparative purposes. The accompanying results, however, have been obtained by observing and recording the reactions with polarised light, as the fragments were successively brought into the field of the microscope. Fragments giving a play of colours in polarised light have been counted as fresh. If they remained turbid or exhibited no play of colours, they have been counted as

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kaolinised. A third group, usually showing a low percentage of fragments is marked off as showing intermediate characters. Some allowance has to be made for variations in the size of the different particles, and it will usually be found that when the results obtained from the examination of thin sections of a sandstone are compared with the results as obtained from the examination of the discrete particles of the same sandstone, a slightly higher percentage of fresh felspars is found to obtain in the former case. Working with polarised light secures the additional advantage of enabling us to recognise at a glance, where fresh, the different felspar species, and to record their proportions in the specimen under examination at the same time.

Various difficulties as regards determination arise. It is by no means always easy to distinguish between kaolinised felspars, and various other decomposed or decomposing minerals and rock fragments. But by combining examination in transmitted, reflected and polarised light, some degree of accuracy may in general be hoped for. The superiority of thin sections will for this reason be evident. Numerous small fragments of volcanic rocks occur in several of the sediments examined—notably in the Torridon sandstones, in several of the divisions of the U.O.R. of Elgin, and in the Reptiliferous rocks of the same area, while they have also been observed in a proportion of the specimens examined from the L.O.R. of Central Scotland. These cause some difficulty when viewed by transmitted light, when seen as discrete particles. But in such cases control determinations have generally been made from thin sections.

Difficulties of determination.

Secondary outgrowths around the felspars in some of the sandstones are *apt* unless attention is specially directed to the point *to complicate the results*, when the determinations are made in polarised light. The secondary fringe gives a play of colours, while the central part constituting the original grain may or may not do so. This has only to be mentioned to secure a correct classification.

A large number of examples have been worked out by the methods just indicated, and the results are tabulated in detail. Most of the sedimentary formations of the North of Scotland have been examined in this connection, including the Torridon Sandstone, the Old Red Sandstone along the southern shore of Moray Firth, as well as from the area of Central Scotland; from the U.O.R. and Reptiliferous rocks of Elgin; while samples have also been examined from recent sands, such as river sands, sea sand, and the blown sand of Culbin, as well as from boulder clays and

Specimens examined.

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post-glacial sands. The number of specimens from each formation is, perhaps, not always so large as might be desired, but they have always, as far as possible, been typical examples of the deposits they represent.

Results in recent deposits furnish key to interpretation of sandstones.

As the results obtained in the case of recent deposits furnish the key to the interpretation of the results obtained from the sandstones, we shall take these first.

It will be observed that the sand of the rivers of the area of the present sea shore, and the sand-dunes of Culbin, show a preponderance of kaolinised felspars, ranging from 64 per cent. in the case of the river Nairn, to 81 per cent. in that of the Spey, while sea sand and Culbin sand occupy an intermediate position—the average of the whole being 73 per cent. of kaolinised felspars. This is the result produced by the influence of the climate of the present day, which is naturally described as moist-temperate.

Recent deposits.

In the case of the boulder clays and post-glacial sands, the difficulty has been to find pure examples—that is examples uncontaminated by admixture with the debris of older deposits. Of the two boulder clays, one from Dulsie Bridge on the Findhorn, which may be considered free from such contamination, gave 86 per cent. of fresh felspars, while the other, with evidence of slight admixture with sandstone debris, gave 83 per cent. A sample of mixed post-glacial sands from localities near Loch-na-bo, and containing a considerable proportion of grains derived from the U.O.R. and Reptiliferous Sandstones, gave 68 per cent. of fresh felspars. Here we have typically illustrated the influence in the one case of a glacial, in the other of a post-glacial climate.

Boulder clays and post-glacial sands.

Applying these results to the problem of the climates of former times we arrive at some interesting, and in one or two cases, very unexpected results.

Last summer while spending a holiday near Kinlochewe I collected from the Torridon sandstones in that neighbourhood a number of rock fragments, which could be seen at a glance to be derived from rocks other than the Archæan gneiss. These fragments are interesting for the information they afford regarding pre-Torridon rocks, and the light they throw on the conditions that prevailed in pre-Torridon times. Among these fragments were many generally well-rounded pebbles of various felsites, showing phenocrysts of quartz, orthoclase and plagioclase imbedded in microgranitic, micro-pegmatitic, and other bases, rhyolites (?) in markedly

Pre-Torridon Rocks.

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angular fragments,[1] and from only one locality showing beautiful fluxion structure and in all stages of devitrification, down even to glassy varieties, various metamorphic schists, quartzites, at least one minute fragment of volcanic tuff, showing Pele's hair, and last, but by no means of least importance from our present point of view, an ovoid pebble of buff coloured sandstone, over half an inch in diameter. Microscopic examination of this fragment showed it to be composed of rounded grains from $\frac{1}{300}$ to $\frac{1}{75}$ inch in diameter, almost all of them, even the smallest, beautifully rounded. The grains have first been covered with ferric hydrate and subsequently cemented together with secondary quartz. Rounded particles of garnet and other heavy minerals are seen at intervals, and the inclusions in the quartz grains, which are numerous and varied, point to derivation from a variety of pre-existing rocks. One of the largest grains is seen to be an ovoid fragment of quartzite showing traces of ferric oxide around its originally clastic grains. The remains of felspar fragments are present but scarce, and they are so much decayed that there is no possibility of determining their specific characters. Accordingly I have put this fragment down as showing 100 per cent. of kaolinised felspars; and the conclusion regarding the climate of the period to which it belonged would be that it was warm and moist, and that the sandstone itself was probably of Æolian origin, or at least that wind was largely concerned in its production.

Climate indicated by pre-Torridon fragment.

In accentuated contrast to this in many respects are the Torridon sediments, in which this fragment was found embedded. These are generally very rough and angular, but I have examined at least one specimen, in which some of the particles would possibly be described as subangular. As these sandstones, in addition to the macroscopic volcanic fragments already referred to, show in all the specimens

Torridon Sandstones.

[1] One of these Rhyolite fragments has given the following analysis:—

SiO_2	74·68
Al^2O_3	11·15
Fe_2O_3	3·36
FeO	1·77
Mno	·84
CaO	2·19
MgO	1·52
K_2O	1·31
Na_2O	1·12
Loss on ignition, CO_2 ·59, H_2O 1·75	2·34
	100·28

The peculiarities of the above result lies in the relatively high percentage of the intermediate bases and the phenomenally low percentage of alkalies. The silica percentage is normal, so also the alumina.

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examined a large number of microscopic fragments of the same rocks, only thin sections have been examined, with the result that 90 per cent. of the felspars have been found fresh, and the degree of freshness they show is most marked. Eight per cent. are noted as kaolinised, but as some of these were seen in association with volcanic fragments, in which they are generally found kaolinised, the inference is that these have been in part derived from them. Microcline is very abundant in these sediments, but plagioclase seems to be rather rare. The results over all show 76 per cent. orthoclase, 16 per cent. microcline, 6 per cent. plagioclase; but some of the latter, being in rather small fragments, may be taken as doubtful. It is probable that a proportion of the latter have been derived from the volcanic rocks then undergoing denudation.

Glacial or subglacial climate in Torridon times.

Now the inference from the felspars—and this inference is borne out by the rough character of the deposits generally—is that a glacial or subglacial climate prevailed during Torridon times—certainly one under which the mechanical rock-disintegrating agencies were in the ascendant. Now is there any evidence from any other source that a glacial climate may have prevailed at this period? We have the authority of Sir A. Geikie that there are certain appearances in association with the Torridon strata in certain localities, that suggest glaciation. 1st. What appear to be *roches moutonnes* on the surface of the Archæan gneiss, where it extends below the Torridon Sandstones, and being therefore of Torridon or pre-Torridon age. Regarding these appearances he asserts: "They have certainly been ground by an agent that has produced results which, if they were found in a recent formation, would, without hesitation, be ascribed to land-ice. 2nd. The presence in Torridon deposits near Gairloch of large angular blocks, up to 5 feet in diameter, arranged so as to simulate a boulder clay so closely that that observer, in company with Sir Norman Lockyer, actually searched the blocks for glacial striæ. There does exist some evidence, therefore, apart from the condition of the felspars, for the existence of a glacial climate in Torridon times.[1]

Other evidence of a glacial climate.

We come next to the Lower Old Red Rocks, and here the chief

[1] Since the above was written I have read in the Society's Transactions with much interest Mr Goodchild's paper on *Desert Conditions in Britain*. A diametrically opposite view as to the origin of the Torridon Sandstones is there propounded. The paper as a whole totally ignores the possibility of fresh felspars being due to glacial as well as desert conditions. My acquaintance with the Torridons, dating only from last summer, does not warrant my going into the question critically, but while admitting the possibility of such origin, I think the facts are rather in favour of the glacial than the desert theory. We do not find, at least I have not found in the specimens examined, any marked rounding of the constituent particles, such as we naturally expect where the transporting

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interest of the inquiry is centred. Not only apparently are conditions of climate indicated, which are at variance with those which, perhaps on insufficient evidence, are generally supposed to have prevailed during this period, but to judge from results decided differences of climate appear to have obtained in the two main areas of the Old Red of Scotland—I mean between the Northern or Orcadian area, and the Caledonian area to the south of the Grampians.

Results in L.O.R. rocks.

The contemporaneity of the two series has been maintained by Sir A. Geikie in his paper on the *Old Red Sandstone of Western Europe*, and again, quite recently, in his *Ancient Volcanoes of Great Britain*,[1] and this in the teeth of complete discordance between the fossil fauna of the two areas. Our results would appear to indicate that the deposits of the two areas were not contemporaneous, as wide differences of climate apparently prevailed during the deposition of the two series. It would indeed be very remarkable, on the hypothesis of contemporaneity, that on opposite sides of the same mountain ridge, and within a distance of one another, at least at one point,[2] of less than twelve miles, two different faunæ existed without a single species in common, while the rivers of the period carried from the same intervening high grounds into the two lakes sediments of such divergent quality.

Differences of climate indicated in the two main areas of L.O.R. in Scotland.

Confining our attention more particularly to the Orcadian area, we have on the principles laid down a glacial to subglacial climate indicated, while the general character of the sediments point no less strongly in the same direction. The first determination, ranking, I believe, the earliest in time, is from the sandstones to the west of Loch Ness. These pass under the conglomerate of Mealfourvonie, and are sediments of the same fineness. Examination of the individual sand particles would go to show that little or no granite is represented in them. Microcline and plagioclase are present, the latter even being of startling freshness, and showing inclusions of the same character, and as brilliantly clear as those seen in the plagio-

In Orcadian area a glacial to subglacial climate indicated.

agent has been mainly wind. I have not seen Pencke's paper on the same subject, but I believe it also cites the conditions at present obtaining in the Sinaitic peninsula as similar to those under which the Torridon grits were accumulated. To my mind there is too great a tendency to assume that at that period of the earth's history things must have been very different from what they are now, and that the temperature of the time was necessarily much higher than at present. For much the same reason the pre-Torridon Sandstone fragment which I have described would no doubt be called a quartzite. At the same time I undertake to produce from the quartz-cemented bands of the Elgin Sandstones specimens in all respects similar.

[1] Vol. i., p. 266 and note.

[2] Stonehaven and Aberdeen.

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clases of gabbros and diorites at the present day. Two sets of orthoclase felspars are present; the fragments of the one set generally show some slight degree of kaolinisation, while those of the other are invariably fresh. We have probably here illustrated the effect of different susceptibilities in the original minerals. The same relations and characters of the felspars are maintained in the matrix of the overlying conglomerate, which is so fine grained and so scanty in quantity, compared with the roughness and angularity of the contained pebbles, as to suggest the possibility of the conglomerate here being an old boulder clay.

Across Loch Ness, near Foyers, we have a series of beds of very different facies. Here the Old Red has been derived all but exclusively from the denudation of the Strathertick granites, but it has been by a form of denudation to which we have no parallel in this country now. The granite has first been pulverised by some mechanical agency, and the resulting debris without material change has then been shot down into one general debacle around the base of the old granitic mountain. The felspars are still fresh, as they are in their native granite, and occur in the proportion of orthoclase, 78 per cent., microcline, 4 per cent., plagioclase, 18 per cent. Only the hornblende of the original granite shows any trace of change. It has apparently gone in large part to make up the dark ferruginous paste in which the other fragments are embedded. Perhaps a parallel to the conditions that have been at work here is described by I. C. Russell[1] as existing on the Yukon, in what he calls *debris streams*. As there, the action of intense frost is probably indicated.

Farther north a sample from Piperhall Quarry has been taken as representing deposits somewhat later in the series and as fairly typical of the sediments in that quarter. This also shows a preponderance of fresh felspars. The facies of the L.O.R. beds to the east is in many respects different.[2]

These show a much lower percentage of felspar fragments. In fact the western L.O.R. beds show on the average 40 per cent. of felspar fragments, the eastern all over only 4 per cent. In

[1] "Surface Geology of Alaska."

[2] *Composition of Sandstones.*

	Quartz.	Felspar.	Other,—schist and mica.
Lower Old Red (east) . .	67%	4	29
Upper Old Red (east) . .	82	16	2
Reptiliferous	90	6	4
Oolite (Lossiemouth) . .	91	8	1
Lower Old Red (west) . .	57	40	3
Upper Old Red (west) . .	77	21	2

The above brings out in a marked manner the differences in composition between the L.O.R. of the east and west, also the local character of the L.O.R. deposits as compared with the generalised character of the deposits of the upper.

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the very earliest of the eastern beds felspars do not occur at all. A specimen from Dipple has been taken as typical of the felspar-bearing sediments in this quarter, with a corresponding result. Again, specimens from each of the outliers of Cullen, Gamrie, and Kildrummy show that they follow the main mass of the Orcadian strata as regards the condition of their included felspars. The Cullen and Tarradale specimens seem to indicate in their increasing proportion of kaolinised felspars a transition to milder conditions as we approach the close of the period, and this is also borne out by a proportionate degree of rounding of the constituent particles of the sediments at these two localities.

In the Orcadian area, so far as the sediments have been examined, we have, according to the principles laid down, a glacial to subglacial climate indicated. We have also, I think, from the increasing proportion of kaolinised felspars, coupled with a certain degree of rounding of the particles, some reason for concluding that there was a gradual transition from conditions of greater to conditions of less rigour as we approach the close of the period. The passage from conglomerates to sandstones of more or less fineness and the comparatively late appearance of life in the series, would also point to the same conclusion. The finer sediments at the base to the west may or may not indicate milder conditions at the very beginning of the period.

In view of the conclusion just arrived at, it will naturally be asked, "Is such a thing likely?" I know of no reason, except a very inconclusive one, depending on the character of the included fossils, for thinking differently. But it is surely an equally good and equally likely hypothesis to suppose that the dermal skeletons of these Old Red Sandstone fishes were an adaptation to keep out cold as to keep out heat. The presence of large angular blocks of rock on the conglomerates, sometimes up to several feet in diameter, fits in very nicely with the supposed existence of glaciers in the higher ravines of the land surface of the period. Farther, we have no means of determining the level of the Old Red lake relatively to the sea of that time, but it is not very likely that such an extensive sheet of water was more than a few hundred feet above that level; but all the evidence we have goes to show that the lake was bounded, at least towards the south, by an elevated plateau, which descended more or less precipitously to the water's edge. Here under naturally temperate conditions at sea level we have presented all the elements necessary to a local glaciation. Indeed the conditions observed at Foyers would be very easily explained on the hypothesis that the granite of Stratherrick, protruding above the general level of this plateau, became a natural feeding ground for glaciers, which,

Other evidence of glacial conditions.

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grinding down the granite of the mountain, gave rise to the appearances now presented by the Old Red beds of that locality. But, if glaciers existed, it may be asked why no glaciated boulders occur in the Old Red conglomerates. Glaciated boulders, even in boulder clays, are comparatively rare, and I am not aware that we have anything in the Old Red—though, as in the instances cited, it may simulate them very closely—that would be accepted as contemporaneous boulder clays without cavil. Rather, I think, the analogy of the Old Red strata is to the post-glacial sands and gravels of the present time. In these, glaciated fragments must be very rare, for though I have repeatedly searched for them in these deposits I have not yet found them. Reference has been made to the corrosions of the quartz grains in many of the L.O.R. beds: I need not say that such action would be eminently fatal to glacial striæ, even granting that they originally existed.

Lake Caledonia.

Passing next to the determinations made from specimens of sandstone from the area of the ancient Lake Caledonia, we find a very different series of results, which are remarkably concordant *inter se*, but differ essentially from the majority of the determinations made in the case of specimens from the Orcadian area. They point unmistakably to milder conditions, and to the operation of the chemical agencies as the chief rock disintegrators of the period. The specimens examined have been from a somewhat limited area horizontally, but they represent considerable differences in time, and it would, no doubt, be rash to conclude that throughout the rest of the area results would be uniformly of like character, but so far as they go they make for establishing the fact that widely different climates prevailed in the two areas, and the natural inference is that the sediments of the two areas were not deposited contemporaneously. This, as already stated, is borne out by the total discordance of the faunæ of the two areas.

The results obtained for the U.O.R. rocks of the Elgin area lead to conclusions scarcely less interesting. Two years ago, in a paper read before this Society, and since published in the *Transactions of the Geological Society of Edinburgh*,[1] I suggested as the result of an investigation of another order, a fourfold division of the Upper Red rocks of the Elgin area. Taking the Upper Old Red rocks of Nairn along with the Elgin Series, we may classify the whole as follows, and, for the sake of comparison, I give in parallel columns the character of the component grains as to rounding or angularity, the character of the included felspars and the characteristic fossils, with their range in time as far as that is known.

Upper Old Red Classification of series.

[1] Vol. vii., p. 148.

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From this table it will be seen that changes in the character of the particles, and in the condition of the included felspars, are accompanied by changes in the fossil fauna of the beds—the whole being the result, in all probability, of corresponding changes of climate.

Variations of climate during period.

The King Steps sandstones of Nairn present characters which link them with the L.O.R. on the one side, and with U.O.R. on the other. In the angularity of their constituent particles they coincide with the Lower, in the prevailing character of their felspars with the succeeding beds of the Upper, but this not in any pronounced degree. Their fossils, however, are, with one exception, which is also found in the U.O.R. of Scaat Craig,[1] different from those of either. These beds are probably best regarded as transition beds between the Lower and Upper beds proper. The climate of the time was probably temperate, but on the whole perhaps less moist than the present.

At Scaat Craig the particles generally are very finely rounded, while the felspars are highly kaolinised. We infer, therefore, at this time the prevalence of a warm and moist climate, with the accompaniment of winds of some force. Fragments of felsite,[2] compact and vesicular, are not infrequent in this series and in that of Newton, which immediately succeeds, and have to be carefully distinguished from kaolinised felspars which, when in small particles, they very closely resemble. In the Newton series the felspars pass to the other extreme, and are there found as pre-eminently fresh as they were kaolinised in the foregoing division. Fragments of graphic granite as fresh as, or even fresher than, specimens taken from the pegmatite veins on the Rothes Burn, from some of which these Newton fragments were probably themselves derived. Neither these fragments nor the large flakes of red felspar from the same locality show any alteration of their surfaces, such as we find in pebbles that have been exposed to the influence of the climate of to-day. Fragments of felsite, which are generally angular, occur up to 4 inches in diameter and down to the size of ordinary sand grains, and pebbles of quartzite, mostly subangular, up to 6 inches diameter, and there are also present fragments of sandstone both from the earlier division of the Upper Old Red of Scaat Craig and from the L.O.R. to the west. The prevailing felspar is a fine red, and has probably been derived in large part from

[1] *Holoptychius decoratus.*

[2] It does not appear to have been noted that the volcanic fragments in the L.O.R. rocks are uniformly porphyrites (diabase); in the U.O.R. as uniformly felsitic, some of the smaller fragments in the Newton being even glassy in character.

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the felspar of Kinsteary granite, though a proportion has been undoubtedly derived from the pegmatite veins of the area to the south-west. Fragments of schist from the same area also occur. We have here indicated, I think, a period of local glaciation during which the neighbouring granitic mountains of Kinsteary and probably also of Ardclach sent down glaciers to the old lake margin. In this connection it is worth recording that the remains of that peculiar fish *Psammosteus Taylori*, which up to the present has only been found in the Newton division of the U.O.R. Sandstone, are found most plentifully in the very roughest beds there. The dermal plates of this fish have been found quite half an inch in thickness, and the association would seem to indicate that this was an adaptation to keep out the cold. Did this cold snap kill off the genus? No Psammosteus remains of any kind have been found in the succeeding beds of the series! The Cornstone succeeds, but it is difficult, on the strength of the felspar determinations, to decide what were the particular conditions of climate then prevailing. It probably represents a period of depression following the period of local glaciation. No fossils have up to the present been found in this division. During the closing or Rosebrae division, to judge from the felspars, a similar climate prevailed. From the degree of rounding of its constituent particles, the fineness of its sediments, which are all but uniformly fine and without a pebble over a distance—probably originally continuous, of not less than twenty miles—from Dallas to Spey Bridge—we would infer that a uniform climate prevailed, warmer, drier and possibly somewhat windier than the present.

Local glaciation at Newton.

Rosebrae, warmer, drier, windier than present.

The Reptiliferous rocks succeed. Reasons for believing that they have been derived in the main from the U.O.R. beds below, from the Rosebrae division in particular, have been given in a previous paper. But as fragments of the same volcanic rocks, mostly of the size of sand grains, are found in them, as in the Newton series, the latter probably also contributed their quota. From the one series to the other, the debris has been transferred by the agency of wind, more quickly, as would be natural—and probably also aided by water—in the early part of the series, as shown by the pebble band at the base containing a higher proportion of fresh felspars. Later, the transference was effected less quickly, as the higher proportion of kaolinised felspars shows that the chemical agencies had longer time to act, though the presence of occasional rounded grains of fresh red felspar indicates that some were more quickly transferred than others. The theory of derivation makes it difficult to

Reptiliferous. Derived felspars. Agency of wind.

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draw any reliable deduction as to climate from the condition of the included felspars, considering that after having been included in the sediments of two different periods they failed to reach a degree of kaolinisation equal to that which obtains under the climate of to-day, and also that wind has been the agent of transport, there is good ground for believing that the climate of the time was warmer, drier, and certainly windier than the present. Some difference in degree between the Cuttieshillock division and the rest of the series appears to be indicated by results.

For the sake of completeness a couple of determinations of the Oolite of the area have been made—one from a small patch of sandstone faulted against the Reptiliferous rocks at Lossiemouth, the other from the Brora area. In the first there is a large preponderance of fresh felspars. This in a fine grained sandstone with markedly angular particles is an anomaly, and probably indicates a warm, dry, and calm climate. These fine sediments have probably been carried by low rivers, their marked angularity generally contra-indicating the operation of wind. The Brora specimen shows some degree of rounding of the grains, accompanied by a preponderance of kaolinised felspars. A change of climate is indicated in the direction of more moisture and more wind.

Oolite. Dry and warm. Variations indicated.

Appended to the paper are tables of results giving the proportions of the different felspars in the specimens examined, along with a series of curves representing graphically the variations in the several formations. These have been traced by first distributing the intermediate group proportionally between the other two, and plotting from 50 as a datum line, *upwards* for a preponderance of *kaolinised* felspars, *downwards* in the case of a preponderance of *fresh* felspars. The curves so obtained show, at a glance the variations of climate that have taken place. For reasons that will be evident they are not to be interpreted purely in the light of temperature charts.

Tables and Curves.

The evidence of the conditions of climate of long past geological periods has hitherto rested mainly on the characters of their animal or plant remains. From this source it is in some cases admittedly equivocal, in others is probably misleading, in many cases is entirely non-existent. If reliable evidence could be obtained from the inorganic side of nature, a point would certainly be gained. With the view of showing that the problem may be attacked from this side, rather than with the intention of recording definite results, has the present paper been communicated.

Evidence of climate from the inorganic side of nature.

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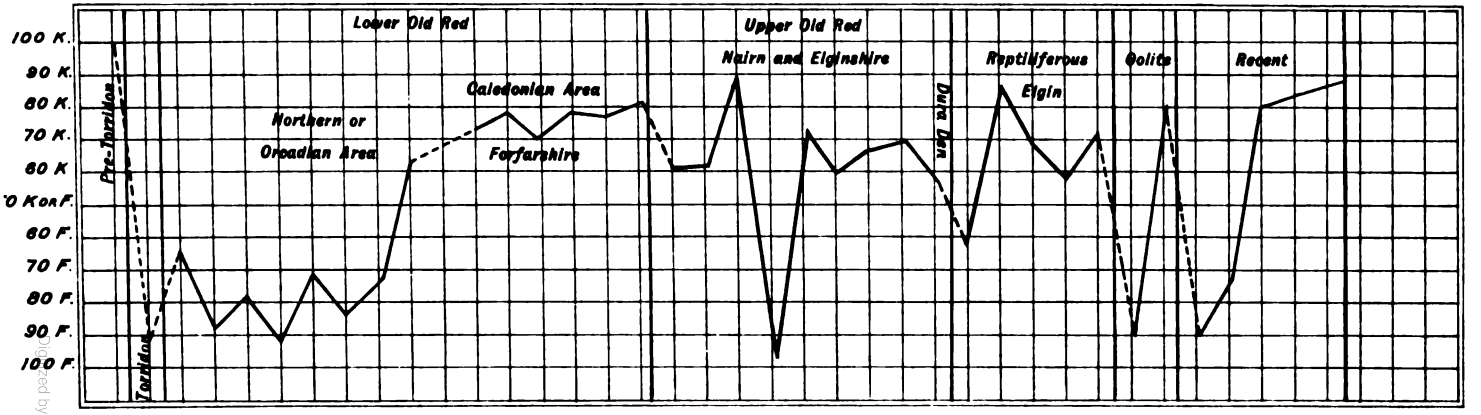
VARIATIONS IN THE PROPORTIONS OF FRESH AND KAOLINISED FELSPARS IN THE DIFFERENT SANDSTONES (GRAPHICALLY REPRESENTED).



F = Fresh. K = Kaolinised Felspars.

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LVI.—*The Hereford Earthquake of December* 17, 1896, *considered in relation to Geological Structure in the Bangor-Anglesey Region.*[1] By EDWARD GREENLY. (Plate XXVIa.)

(Read 7th April 1898.)

CONTENTS.

1. PHYSIOGRAPHY.
2. ROCKS COMPOSING THE DISTRICT.
3. STRUCTURAL RELATIONS.
4. SEISMIC EFFECTS OBSERVED.
5. CONCLUDING CONSIDERATIONS.

1. *Physiography.*—Broadly speaking, Carnarvonshire and Anglesey consist of portions of two ancient and deeply denuded plateaux. The higher of these, which may be called the mountain plateau, is part of that very extensive massif out of which has been sculptured the mountain country of North Wales as a whole. It ends off somewhat abruptly in Carnarvonshire along a NE.-SW. line drawn from near Conway towards Nevin, and passing a little to the NW. of Llanberis. Seen from Anglesey its profile appears as that of a very flattened dome, some forty miles in length, and reaching a maximum elevation of 3500 feet. The lower plateau has an average height of about 300 feet, and comprises the island of Anglesey and a part of the mainland some four miles wide, lying to the NW. of the line above mentioned, and may be called the Bangor-Anglesey or the Menai plateau. The Menai Strait is merely the deepest of a series of well-marked NE.-SW. valleys by which it is traversed.

2. *Rocks composing the District.*—The mountain plateau is composed of Cambrian and Ordovician rocks (the latter largely volcanic), all of which are more or less cleaved and hardened by compression, forming a thick and very resistant mass.

The Bangor-Anglesey plateau, with which we are more immediately concerned, is composed of rocks which for seismological purposes may be grouped as follows:—

Glacial Drifts.
Carboniferous rocks.
Ordovician series.
Bangor volcanic series (in Bangor area).
Schistose Complex.

[1] The results and suggestions given in this paper occurred to me while collecting reports for Dr Charles Davison, owing to whose kind encouragement I have ventured to publish them. I believe I may be permitted to add that abundant material for much more extended enquiry of the same kind will be provided in a work upon this Earthquake which Dr Davison is now preparing.

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The Glacial Drifts lie chiefly in the valleys, where they reach a thickness, occasionally, of as much as 100 feet.

The Carboniferous series has a maximum thickness of about 2900 feet, of which 1100 feet are limestone, the remainder being sandstones and shales belonging chiefly to the Coal-measures and the Millstone Grit. The limestone group includes some beds of sandstone.

The Ordovician rocks are chiefly black shales and brown sandstones, rather soft. For seismological purposes it must be observed that this series has a very different character in the Bangor-Anglesey area from that which it has in the mountain region. There it is cleaved and hardened by pressure, and contains immense masses of igneous rocks in bed, sills, and bosses. Here cleavage is faint or absent, and there are no igneous rocks of structural importance, so that the whole series is much less hard and resisting.

The volcanic group of Bangor (Cambrian or pre-Cambrian) consists of large masses of felsite and a series of bedded pyroclastic rocks varying from breccias with large blocks of lava to fine laminated halleflintas, all very hard and resistant.

The pre-Ordovician rocks of Anglesey are for the present purpose regarded as a structural unit, because although exceedingly various in character, they appear to be all more or less foliated. The types most prevalent are rather fine chloritic and micaceous schists, but there are large masses of quartzite and complex granitoid and gneissose rocks, as well as considerable areas which are described as slaty rather than as schists truly crystalline. The series, however, in all but the farthest N. and NW. portions of the island, may safely be regarded as bound together by a common foliation, and possessing the character of a crystalline foliated complex.

3. *Structural Relations.*—Along the line where the mountain region adjoins the Bangor-Anglesey area, Cambrian slates and grits dip SE. at high angles, from 60°-90°, so that whatever views be held on certain stratigraphical points still under controversy in the last-named region, there can be no doubt but that those grits and slates must plunge rapidly down just within the mountain area, and pass underneath the great Snowdonian syncline at very great depths below sea level.

Between the mountains and the Straits the ground is occupied by large masses of felsite, and undulating beds of grit and slate, till a large NE.-SW. fault brings in softer Ordovician shales, which form a broad valley deeply laden with drift. In the immediate neighbourhood of Bangor (see Map, Fig. 1.) the volcanic rocks above mentioned emerge, dipping at very high angles, from beneath these shales, forming a steep and

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rocky hill. A valley succeeds, in which are Ordovician shales again, apparently bounded by two NE.-SW. faults which coalesce near the Railway Station; and in this hollow lies the old city of Bangor. Upper Bangor stands on another NE.-SW. range of hill, also composed of the volcanic rocks, beyond which, bounded by a fault with a maximum throw of some 1800 ft. and forming a very marked feature, comes the Carboniferous Limestone, dipping at moderate angles generally to the SE. It forms an undulating tract of country along the shores of the Straits, which are about 40 ft. deep.[1] In Anglesey, the Schistose Complex appears in four main areas, separated by strips of Ordovician and Carboniferous rocks. The structures in the Schistose series itself are exceedingly complicated, far too much so to allow of any attempt at present to treat it, for seismological purposes, otherwise than as a structural as well as lithological unit. Suffice it to say that it is intensely and minutely contorted, and that its constituents are, so far as I myself know them, interfelted in the manner that is characteristic of crystalline schists, and which must certainly influence the transmission of vibrations in a different way from the structures of either ordinary igneous or sedimentary rocks. The Ordovician rocks overlie them unconformably, and are disposed in what are probably much disturbed synclinal areas, ranging for the most part NE.-SW., and apparently of considerable depth, the dips being often at high angles close to the junctions. The Carboniferous rocks again, lie unconformably upon them and all the older rocks. The principal mass (see Section, Fig. 2) lies in a semi-syncline bounded on the SE. by a very large fault or system of faults ranging completely through the island from Redwharf to Malldraeth Bay. This fault has a throw of 2300 ft., and the Carboniferous strata descend to more than 2000 ft. below sea level.

The strikes, throughout the whole Bangor-Anglesey area, are for the most part NE.-SW. The dips, moreover, it may be noted, are (not

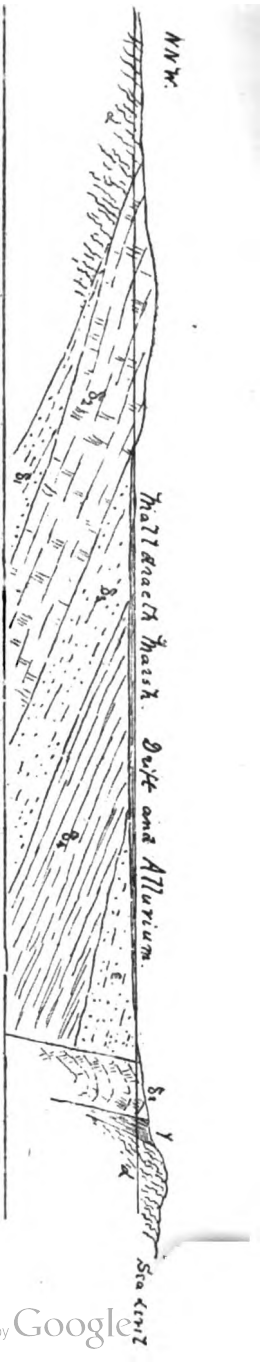

FIG. 2.

[1] There is reason to suppose that, Eastward of the Tubular Bridge, the floor of the Straits is composed of Ordovician shales (Geol. Mag., 1898, pp. 560-562). To the SW. of that Bridge, Carboniferous rocks probably form the floor.

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considering those in the contorted Schistose Complex) generally to the SE.; except in the large Ordovician area of Llanerchymedd, when the prevalent dip is NW.

The difficult question of the age of the Schistose rocks cannot for seismological purposes be altogether ignored. They have been variously regarded as Pre-Cambrian, as Cambrian, and as including possibly both of these with even Ordovician rocks as well, by different authors. Now it is manifest that, if Pre-Cambrian, this complex must be part of an old floor on which all the other formations, of the mainland as well as of Anglesey, repose, and through which, therefore, all the seismic vibrations must have been transmitted. If Cambrian, the same condition holds good, though the mass itself might be of less depth. But if in great part Ordovician, such rocks might be but a thin skin in which the condition for the transmission of vibrations might not differ seriously from those in the sedimentary masses of known age in the area.

Fortunately, however, it is the N. area concerning whose age there is the most doubt; there having been of late apparently a tendency to a general consensus of opinion that the Central and SE. regions are of Pre-Cambrian age; and these were the only portions in which I have any evidence of the shock having been felt. But the question cannot yet be regarded as settled.

4. *Seismic Effects observed.*—The reports[1] show clearly that the intensity of the shock diminished rapidly in a NW. direction, the last reliable records which I have obtained having been from Trescawen, near Llangwyllog, and Aberffraw on the W. coast. All replies from observers situated further to the NW. have been in the negative. In the mountain country, on the contrary, it appears to have been generally felt. Therefore the SE. portion of the Bangor-Anglesey area, a zone about fourteen miles wide from SE. to NW., seems to have been a region in which the sensible effects of the shock were dying out.[2]

Now, allowing for gradual decrease of intensity as shown, the varying reports seem to show that, within this zone, the shock was felt most powerfully in houses standing upon the Carboniferous and Ordovician rocks, less so in those upon the hard volcanic series of Bangor, and least of all in those upon the Schistose Complex of Anglesey.

Were it possible to draw the isoseismals with accuracy, we

[1] The following remarks are based not only upon the written reports (some 40 in number) sent in, but upon enquiries made in Anglesey by several persons, covering considerable areas in parts where little or no shock was felt.

[2] Dr Davison tells me, however, that it was felt further out from the Epicentre, in a NW. direction.

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should probably find them sharply incurved around the areas occupied by the last-named rocks, or inliers even occurring of outer and lower isoseismals.

Moreover, all reports of the shock having been felt within the Schistose areas are from observers situated close to the margins of those areas, *i.e.*, to junctions with Carboniferous or Ordovician rocks. General reports from the heart of the Central area seem to show that it was there scarcely felt at all, while the reports from Tregaian and Bodorgan are near junctions. Much more remarkable is the immunity of the SE. region, throughout the heart of which I cannot find that any shock at all was felt, while from stations on its *outer* edge considerable disturbance is reported. Moderate disturbance is reported from the margin of the Straits, again near the margin of the Schistose complex; and in "Menai Bridge," a large village or small town where I know many people, I have only been able to find one person who felt anything, although from a house at the Carnarvonshire end of the Bridge, on the Carboniferous Limestone, a very decided shock is reported.

It is to be noted that not only are the Carboniferous and Ordovician rocks probably far less elastic than the crystalline schists, but that they are also (as about Beaumaris) much more deeply covered, as a rule, with Boulder Clay.

In the Bangor area itself, although the shock was felt upon the hard volcanic series, there is a general agreement among all persons that it was far more strongly felt in Lower or old Bangor, *i.e.*, on (or within a few yards of the boundaries of) the faulted wedge of Ordovician shales (see map and section). It seems also to have been more felt upon the Carboniferous rocks near the Straits, so far as I can gather, than upon the old volcanic series.

With regard to faults, I cannot discover the slightest connection between the shock and any of the larger faults which traverse the district. My own house is built as nearly as possible *upon* one of them, but none of my household felt it at all. It is true that in Anglesey some of the boundary lines near which the shock was felt are faults, one a very large fault; but the connection appears to be with *boundary* rather than with fault, for the increase in intensity is quite as marked at junctions which are certainly not faults (Bodorgan), and near others (Beaumaris, Menai Bridge, Llanfair, Tregaian), which may not be faults at all, or, at any rate, not large ones. Indeed, the movement seems to have been propagated through the district in a direction normal to the fault planes, and so across them, modified only by their presence as vertical or highly inclined junctions between rocks of different character.

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A certain number of observers have given their impressions (nearly all unsolicited) as to the *direction* of the movement. I have plotted these upon the maps, and it will be seen that they are all from somewhere between E. and S. Allowing for personal error in a matter which I should think very difficult to be sure of, and also for actual variation through a moderate angle, there is a fairly general agreement as to movement from a SE. direction. I cannot correlate the discrepancies with any facts such as nature of rock, dip, or strike, for the differences are often between observers on the same strata. But perhaps the rapid variation in material, especially in the Bangor area, and the way in which it is traversed by large faults, which must be vertical junctions, are quite sufficient to produce these deflections.

Concluding Considerations.—A full explanation of the facts here recorded is, I suppose, at present impossible, and would in any case be a task rather for the seismological specialist than for the geologist. A few considerations, however, naturally occur.

The general result that the shock was felt inversely to the degree of elasticity of the rocks is in accord with previous results obtained in cases where the contrast was much greater and the effects of the shocks more obvious.

Next: that, on the rocks least affected, the shock should be felt more powerfully near large boundary faults is not difficult to understand. The whole district is far removed from the epicentre, and the impulse must therefore have been propagated at a low angle to the horizon, thus meeting the fault planes at angles not much less than 90°; so that any effects due to reflection would tend to be well marked. The reason is less clear, however, why a similar exaggeration should be observable, as seems certainly to be the case at Bodorgan, where the margin of the metamorphic rocks is simply the present outcrop of the base of an unconformably overlying series. Why should the schists be more perceptibly shaken because some half mile away they are *over*lain by later limestones, shales, and sandstones? It is certain, however, that an impulse propagated at a low angle to the horizon, and from the SE., would (see Fig. 2) have had to pass through the mass of the Carboniferous series before entering the crystalline schists of Bodorgan. For any such impulse to escape that path, it must have been travelling at more than 20° to the horizon. The impulse, therefore, would in this case also have had to pass from one series of rocks to another, though at a very much smaller angle to the plane of junction than in the case of the faults. Whether this may be really sufficient to account for the observed facts, I do not

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know, but commend the case to the consideration of seismologists.

Is it possible, also, that the prevalent SE. dip of the stratified rocks may have assisted the transmission of undulations propagated at a moderate angle upwards from the SE.? And may the fact that the Ordovician rocks of Llanerchymedd dip NW. account for the vibrations disappearing altogether NW. of Trescawen, and not reappearing (though of course in any case *near* their extinction) at all in the usual way near the junction with the schists?

With regard to the stratigraphical position of the Schistose Complex, a most important question arises. If it be true that this complex is of pre-Cambrian age, then (as we have said) it must form a floor upon which all the other systems in the district repose; and therefore, before the seismic impulse could have been communicated to any of these, it must have traversed the crystalline schists. The problem, then, presents itself as to why the shock should be less felt after transmission through crystalline schists alone, that is, in the regions where they reach the surface, than in districts where they are covered by later deposits. For, in any case, the shock must have travelled through the schists first, and its final passage through 1000 feet or more of less elastic and stable rocks would seem to have increased rather than diminished its intensity.

Finally, in this connection there is a curious consideration that may be of some importance. All the older Palæozoic rocks, and *a fortiori*, the Archaean floor beneath them, descend to great depths in the bottom of the Snowdonian synclinal fold. That axis passes about midway between the sections in Merioneth and Carnarvonshire from which the thickness of the lower parts of the series have been measured; so that it is reasonable to suppose that the Cambrian system has there a thickness intermediate between those it displays at the measured sections. If we calculate this thickness at 9600 ft., and add it to that of the depth of the base of the Arenig slates [as shown in Sir A. C. Ramsay's section (Mem. Geol. N. Wales, Geol. Survey)], we find that the surface of the Archaean floor in the lowest part of the great syncline cannot be less than 17,600 ft. below sea level. Protracting the angle which this makes with the point of emergence of the Schistose Complex on the shores of the Menai Straits, we find it to be not less than 16°-17°. In the case of a seismic impulse reaching Anglesey at a low angle from a centre far distant to the SE., it would appear that this structural fact must have some influence.

It is customary to sum up a paper with a paragraph of

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"conclusions." The present communication, however, would be better summed up in one of "interrogations." But, as a geologist, it appears to me that much may yet be learnt concerning the influence of geological structure on seismic manifestations: especially in districts where we have any correct knowledge of that structure at considerable depths below the surface.

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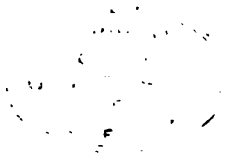

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LVII.—*On an Ash Neck in the Broxburn Shale Workings at Philpstoun.* By HENRY M. CADELL, B.Sc., F.R.S.E., F.G.S. With an Appendix by J. S. FLETT, M.A., B.Sc.

(Read 7th April 1898.)

WHILE revising the Geological Survey Map, Sheet 32 (including the oil shale fields between Edinburgh and Linlithgow), several years ago, I had reason to alter the mapping of numerous outcrops of tuff, shown on the first edition of the sheet as lenticular beds, and to indicate them on the new edition of the map as volcanic necks more or less circular in plan. At that time, so far as I was aware, there were no perfectly clear natural sections in the district showing the walls of the old volcanic pipes and their relation to the surrounding sedimentary rocks. There was therefore still some little room for doubt as to the true character of such volcanic outcrops. In 1896, however, an excellent section of a true volcanic neck was revealed in the workings of the Philpstoun Oil Company in the Broxburn shale seam. While driving a level at a depth of about 120 feet below the surface in this seam of oil shale, the miners found the dip of the strata to change suddenly from north to east. The trend of the level-course (which coincides with the strike) was at first, roughly speaking, an easterly and westerly one, and as the level was being driven towards the east, the change of dip caused it to swing round to the south, and it was followed for some distance in this direction. A cross-cut was then driven south-eastwards from the roof of the seam horizontally through the strata, and after penetrating a few yards into the overlying strata the miners were suddenly confronted by a vertical wall of hard volcanic material, somewhat slickensided, like the face of a fault. The mine was driven right through this obstruction, and after about a year and a half of laborious work the shale was found on the other side in good condition, but dipping towards the north-west at a steep angle. The walls of the neck were quite perpendicular, and the thickness of the volcanic plug was 360 feet from wall to wall along this line of section. Several bores had been previously made on the surface of the ground near the place, and some of these struck ash where shale was to be expected, while others near them

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reached the shale in its normal position. The ground is covered with drift, so that no rock is exposed at the place, and therefore the results of the borings were at first very difficult to understand, but the whole problem was satisfactorily solved by the operations just described in the workings beneath.

The neck is oval in plan and about 700 feet in thickness along its greatest diameter, and is situated immediately below Gallowscrook, half a mile NE. of Philpstoun station. It is one of the many plugs of volcanic ejectamenta that pierce the Calciferous Sandstone strata in this district, some of which, like this one, are no doubt concealed below the drift, but others, such as the Tor Hill at Ecclesmachan, project like knots in an old and well-worn floor.

Through the kindness of Mr A. H. Crichton, the manager, I was enabled to examine the exposure in the mine more than once. There was little or no evidence of contact-metamorphism or thermal action to be seen. The oil shale was almost unaltered to within a foot or two of the neck, but at places it showed some signs of induration by heat in the immediate neighbourhood of the ash. The line of division was perfectly sharp and regular, and the surface of the volcanic rock showed signs of having subsided after consolidation and drawn down the surrounding strata, so as to make them dip inwards on all sides like a funnel. The actual junction was occupied by a few inches of crushed shale or soft breccia, such as is common on the hanging walls of faults.

The tuff itself varied greatly in character and structure. It was mostly fine grained and light coloured, and was at places excessively hard, almost flinty in texture, but when exposed to the weather it soon crumbled down into sandy mud. Here and there it was impregnated with iron pyrites and contained large blocks of black shale and other sedimentary inclusions, or again, it was interspersed with small drusy cavities or veins of pitch or solid paraffin, derived no doubt from the distillation of the hydro-carbons in the shale. It is not necessary to describe the petrographical character of the tuff, as Dr Flett, who made an examination of specimens from different parts of the section, has kindly supplied the appended results of his investigation.

Ash necks such as this suggest several interesting questions. Sir A. Geikie, in his valuable work on the Carboniferous Volcanic Rocks of the Forth Basin,[1] deals at some length with the volcanic necks of this part of Scotland, and refers to the pieces of wood of coniferous trees that are often found embedded in the ash. These fragments show that the volcanoes during

[1] Trans. R.S.E., vol. xxix. p. 455.

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periods of quiescence were clothed with vegetation which was shattered during later eruptions to the splinters and blocks now found buried in the tuff. When trees grew on the volcanoes the cones must have been above sea level, but I have also found in the ash of some of these necks rounded quartz pebbles over an inch in diameter,[1] and the ash of this particular neck contains a considerable quantity of quartz sand or fine gravel mixed with the calcareous and felspathic ingredients. Materials of this nature evidently show that this was a submarine volcano, or at least that it burst out under a sandy or gravelly surface, such as an estuary, where the current was strong enough to move along coarse detritus.

Another interesting point is to be noted. Whenever we find a neck or volcanic pipe filled with ash alone, like this one, and containing no crystalline eruptive rock, it is clear that we are more or less near to the crater or orifice of the old volcano. Ash or volcanic dust and scoria is produced by the rapid expansion of the water in the lava as it rises to the surface and permits the water to flash into the gaseous state and blow the melted rock into small fragments by the force of the explosion. The lower part of a volcanic pipe is full of melted rock, and it is inconceivable that ash can fill it to any considerable depth. The ash that drops down into the heated depths will become fused up again where the temperature reaches that of fluid lava, and only the upper and colder part of the column near the surface and below the crater, will continue to remain in the clastic state.

Volcanoes are generally found near water, and in some cases, such as that of Mount Tarawera in New Zealand, it seems pretty certain that eruptions have been originated by the water finding its way down in large quantities to the heated lava below, and causing it to expand and burst up at weak spots or along fissures.[2] As soon as the pressure is sufficiently relieved the steam will explode with terrific force, blowing out large craters along the fracture or line of weakness. No lava reached the surface in the case of Tarawera, but prodigious quantities of scoriæ and lapilli were thrown out, and pieces of slaggy lava were splashed against the sides of the craters, showing that this rocky matrix was the parent of the dust and ashes, and proving that the latter could not fill the vents to any enormous depth. At present the principal craters of Tarawera are huge pits whose walls are nearly vertical, with depths reaching, in some cases, to over 800 feet. The bottom

[1] See author's paper on the Volcanic Rocks of the Borrowstounness Coalfield, Trans. G.S.E., vol. iii., 1880, p. 313.

[2] See the description of this volcano in Trans. G.S.E., vol. vii. p. 195.

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of these is filled chiefly with ash and loose materials that have fallen in after the expulsive force of the eruption had so diminished as to prevent the escaping gases keeping the vents clear. How far down the plugs of ash may extend it is impossible to ascertain. Lava can be seen in the bottom of one or two of the craters on the summit, but other craters, such as that now occupied by Lake Rotomahana at the foot of the mountain, were originally huge holes whose bottoms were over 3000 feet below the edge of the highest crater. If, therefore, the upper part of the lava under the mountain did not rise as a whole to a higher level than the deepest part of the great crater of Rotomahana, the ash plug in the high level vents may reach down to depths of at least 3000 feet from the summit, 800 feet of which remains still open, and liable in time to become filled up with the products of ordinary subaerial denudation. From this point of view an ash neck might pierce strata 3000 feet in thickness or more. But there are, on the other hand, many examples of volcanoes whose lava has risen to the very surface and welled quietly over without producing any ash at all, like many of the cones in the Rocky Mountain plateaus.

Where water is plentiful the probability is that the explosive force will be great owing to the greater quality of expansive gases present, and therefore the tendency will be to produce more ash than lava. Now during the Carboniferous period the volcanoes were at first submarine, and thus we should expect more ash than solid lava among the products of their earlier eruptions. This is what we find in West Lothian more especially. The necks are mostly of ash mixed with sand and fragments of the underlying rocks, and above the horizon of the Houston Coal there are beds of green and red marl, mixed at places with fragments of tuff which mark the first series of eruptions that were continued throughout almost the whole of the Carboniferous Limestone period. The so-called Houston Marl appears to be a bed of exceedingly fine-grained volcanic mud produced by the decomposition and rearrangement by water of extensive eruptions of ash over a wide district. It occurs at a higher horizon than the Broxburn shale, and I am inclined to think that some of the ash necks that pierce the beds below the Houston Coal may be the source of the marl above the seam.

The majority of the necks, however, including the one at Philpstoun, are most likely connected with the sheets of interbedded basalt and diabase of the Carboniferous Limestone series a few miles to the west, or more probably they represent the remains of volcanoes of the same age in the immediate vicinity, the upper parts of which have, with the sedimentary beds surrounding them, been entirely denuded away.

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Appendix by John S. Flett, M.A., B.Sc.

Of the various hand specimens of rocks from the Philpstoun neck which I examined and prepared sections of, there seemed to be three principal varieties sufficiently well marked to be described separately. The freshest of all was a fine-grained, reddish rock, evidently largely arenaceous in composition, and filled with fragments of dull-brown volcanic rock, angular, vesicular, and on an average, of the size of a pea. The microscope showed this to be an ashy sandstone, the sand grains well rounded, and evidently the product of the disintegration of areas of granite and gneiss. Weathered felspar in small quantity was present among the sand grains. The volcanic fragments were peculiar in consisting entirely of a clear brown volcanic glass, full of cavities, and with only minute felspar microlites. The glass was still so fresh and unaltered as to be perfectly isotropic. It resembled closely some of the basaltic pumices of the Sandwich Islands.

The second group of these rocks were black, with large irregular white spots. The black material was evidently a comminuted shale with a small quantity of sand. The white spots turned out to be basaltic lapilli so entirely decomposed that, though their original constituents could be pretty well identified, not one of their characteristic optical properties was to be observed. They had in fact suffered the "white trap" modification so common in intrusive basic sheets which penetrate oil shales. In the highly turbid material composing them the ghosts of felspar and augite crystals could be recognised by their shapes, but no trace of the original minerals remained, all having been converted into kaolin and calcite.

The third series was white or dull grey in colour, with cavities often lined with sticky plastic bitumen. These were similar rocks to the preceding, but with much less admixture of dark shale. Some may have been intrusive veins, but others were true hoffs. Compared with white trap proper these rocks had the hemicrystalline porphyritic structure of the basalts as against the coarser diabase structure. Around their numerous cavities were dark opaque rims which disappeared on heating the section to bright redness, and were no doubt bituminous organic matters. Within these calcite was usually deposited, a feature which proves that the bitumen was produced probably while the fragments were still hot, and, at any rate, before the infilling of the vesicles of the volcanic lapilli.

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LVIII.—*On Phenocrysts of Micropegmatite.* By JOHN S. FLETT, M.B., B.Sc., Edin. (Plate XXVII.)

(Read 21st April 1898.)

THE occurrence of phenocrysts of micropegmatite in acid igneous rocks is of sufficient rarity to make every new observation worth placing on record. In two cases they are known to be present in British rocks—in the ancient felsite of Woodwick, near Fishguard, Pembrokeshire, as shown by Mr F. R. Cowper Reed, F.G.S.,[1] and in the granophyric quartz-porphyries of the Cheviots mentioned by Mr Harker [2] as shown him by Mr Kynaston. From America Professor Iddings has described two occurrences, one from the recent rhyolite of obsidian cliff, the other from the rhyolites of the Eureka district.[3] In Zirkel's "Lehrbuch der Petrographie," ed. 2, several instances are cited (p. 150 and p. 223), but he takes occasion to remark on their great rarity. As they have come under my notice in three different rocks within a comparatively short time, it is probable that after all they are more common than is generally believed, as certainly they are of wide distribution in acid rocks of hemicrystalline character.

In a slide of the well-known Liparite of Hlinik in Hungary, in the Edinburgh University Collection, occurs a single section of a micropegmatite phenocryst. In the many slides of this rock I have examined I have found no other. In ordinary light it exactly resembles the corroded and broken sanidine crystals which are abundant in the rock. Its outlines are irregular, but not more irregular than theirs. But in polarised light it is seen to be a sanidine with the characteristic cleavage cracks and penetrated by numerous inclusions of quartz, some of which are triangular but others shaped like the letter L (see pl. xxvii., fig. 1). These extinguish simultaneously and yield the same polarisation colours throughout, with the exception of three or four which seem to have also a common extinction differing very slightly from that of the majority. Both quartz and sanidine contain glass cavities filled with the brown

[1] Reed, *Quart. Jour. Geol. Soc.*, vol. li. p. 162.
[2] Harker's "Petrology for Students," ed. 2, p. 110.
[3] Iddings, 7th Annual Report of the U.S. Geological Survey, p. 274, pl. xv. Iddings, Monograph xx., U.S. Geological Survey, p. 375, pl. v. fig. 2.

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glass which forms the rock matrix. Felspar forms the chief part of the aggregate and envelopes the quartz, but the irregular border is formed by the edges of areas of both minerals, and there seems to have been no final rim of felspar, or if formed, it has been removed by the corrosion to which the phenocrysts have been subjected.

The pink felsite of the Black Hill, Pentlands, is a rock well-known to Edinburgh geologists. It forms a mass intrusive into the Old Red Sandstone series, and the specimens examined were mostly collected from the outcrop on the left side of the path from Bavelaw to Loganlee Reservoir. It is sometimes lustrous and very fresh in appearance, but in other cases dull and spotted with small pale spots. It was found that the latter specimens were comparatively rich in micropegmatite phenocrysts, which were less common in the lustrous rock. Microscopic sections show that this is a microgranite with a holocrystalline ground mass consisting of small, irregular-shaped grains of quartz and orthoclase, stained red with a deposit of limonite and hæmatite, and filled with small flakes of muscovite, probably of secondary origin. Orthoclase, plagioclase and quartz are present as porphyritic crystals, never of large size. The former presence of biotite is indicated by occasional pseudomorphs of chlorite filled with rutile (sagenite) and other dark substances, and showing the outlines and cleavage of dark mica, and in a few cases the mineral is sufficiently fresh to show its optical properties and pleochroic halos.

In this rock phenocrysts of micropegmatite are very numerous and of relatively large size, and in most respects closely resemble those described by Iddings from the Eureka district, Nevada (see pl. xxvii., figs. 2, 3, 4). The intergrowth of quartz and felspar is on a scale so minute that the thinnest sections are required to render it evident. Many of these crystals are compound and consist of a group of individuals joined together and radiating from a common centre. Here and there occur masses of quite irregular outlines resembling some of those figured by Mr Cowper Reed. Comparatively few show any trace of the outlines of quartz, but some have a lozenge-shaped outline resembling the section of a double hexagonal pyramid, and in these the extinction is parallel to the diagonals. Felspar is here again the dominating mineral and forms the matrix in which the quartz lies embedded in masses generally of wedge-shaped outline, and the most perfect phenocrysts are those which clearly show the outlines of orthoclase felspar. (See pl. xxvii., fig. 4.)

The faces commonly represented are 110, 010, 001, $10\bar{1}$, (l, M P, x), and Carlsbad twinning is frequent. The crystals

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are tabular on the clinopinakoid. The felspar forms also in many cases a clear border around the phenocryst, which is so fresh and unweathered as to be difficult to distinguish from quartz except by using a gypsum plate. A similar border is found around many of the ordinary felspars of the rock, and to the presence of this rim of later felspar must no doubt be ascribed the very great perfection in which the micropegmatite phenocrysts show the outlines of felspar. It indicates also a complete absence of chemical resorption during the later stages of consolidation which is rather unusual.

The felspar of these aggregates is never plagioclase though that is not unfrequent in the rock. In a few cases, however, a small plagioclase has been found to form a nucleus around which micropegmatite has crystallised. More usually an orthoclase forms such a nucleus, though most commonly there is none, and the aggregate consists simply of micropegmatite with a peripheral zone of clear felspar.

In the consolidation of this rock the following have obviously been the stages—

I. Crystallisation of mica, plagioclase, orthoclase, quartz, as phenocrysts.

II. Formation of micropegmatite by simultaneous separation of quartz and orthoclase from the magma, deposition having taken place around pre-existing felspars in some cases but not in others. The crystallisation of the felspar has out-lasted that of the quartz.

III. Formation of the microgranitic ground mass.

If we compare this with other rocks showing graphic intergrowths of quartz and felspar we have the three following types : —

a. In which the whole rock is graphic, *e.g.*, graphic granite. Stage II.

b. In which the graphic structure is confined to the ground mass while the rest of the rock is crystalline. This is the usual type and represents Stages I. and II. above, *e.g.*, granophyre, many granites, etc.

c. The type represented by the Black Hill Felsite, in which the formation of micropegmatite is merely an episode in the rock's history, and does not continue till consolidation is complete. This seems to be exceptional in the natural history of igneous rocks. The micropegmatite may form irregularly shaped aggregates—though these are possibly corroded phenocrysts—or may have the outlines of felspar, as that is usually the dominating mineral, and is the last to cease crystallising.

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A point of great interest in these micropegmatite aggregates is their very perfect hour-glass structure (figs. 2, 3, 5), which, when the intergrowth is on a minute scale, closely imitates that of many rock-forming minerals, such especially as occurs in the augites of basic rocks. This results from the shape and disposition of the areas of quartz, which are elongated with their long axes perpendicular to the four faces by which the crystals are usually bounded, as seen in section. Hence in such a section the quartz strings tie approximately in two systems crossing at right angles. A similar appearance may be obtained by taking a piece of notepaper and drawing lines on it perpendicular to its sides. If two diagonals be then drawn from corner to corner these will form the boundaries of four areas, the opposite two being similar, while any contiguous two are dissimilar. Unlike the "spherulites" of many granophyres these strings of quartz are not truly radiate in disposition. During the whole history of these growths they must have preserved crystalline outlines, the boundaries being similar to those shown by the completed structure, and the outermost layer consisting of patches of quartz alternating with felspar. As the crystal enlarged, these areas must have gradually broadened, hence the generally wedge shape of the quartz patches, the apex being inwards, the base outwards. New areas of quartz were also occasionally formed, as there are more wedges in the periphery than in the centre of the crystal. In some cases this structure is not very perfect, the quartz in places having an irregular arrangement, but in many it is very marked, and the specimens figured by Iddings show the same feature. This suggests that the hour-glass structure of many apparently simple minerals may have the same explanation. Such crystals are generally regarded as having first been hollow, like "hopper-shaped" crystals of rock salt or hollow ice crystals, the result of a more rapid growth of the edges than of the centre of the faces, and subsequently to have had these spaces filled up with a deposit of slightly different composition and optical properties. To this theory of their origin there is an obvious objection that crystals with hollow ends are most usual in the minute crystallites of glassy rocks, and are never of such size as the large hour-glass crystals, and it would have been naturally expected that crystals with ends imperfectly filled up should be not uncommon. But these crystals are not really simple, but consist of isomorphous admixture of two or more allied minerals, as is seen also by their general zonal structure. If then we suppose those minerals to have intergrown in the same way as the quartz and felspar in the micropegmatite aggregates, the one lying in strings and wedges imbedded in the

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other, and these to lie mostly perpendicular to the faces which bound the crystal, we have an explanation which at any rate is in accordance with the observed facts. That the microscope does not reveal such a structure in the case of hour-glass augites and other minerals, may be due to the fact that the component isomorphous silicates do not differ so markedly in optical characters as do quartz and felspar, and also to the structure being, as in many cryptoperthite felspars, ultra-microscopic in minuteness, as some of the micropegmatite aggregates in this rock in all probability are.

Another question of great interest raised by these structures is whether there exists any definite relationship in the relative positions of the crystallographic axes of the minerals composing them. In two minerals so closely associated it is more usual to find that some method of parallel growth is present than the contrary, as, for example, between muscovite and biotite, orthoclase and plagioclase, hornblende, augite, and hypersthene. Here the minuteness of structure baffled all attempts to get satisfactory interference figures to settle the point, as was found also by Iddings in the Nevada rocks. But it is worth observing that should a parallel growth between them exist, it can only be of one kind. Many of the felspars are Carlsbad twinned, and throughout a section of these the quartz extinguishes often simultaneously. The principal axis then of the quartz must have such a position in the felspar that it is not modified in direction by the twinning. Three directions are the same for both halves of a Carlsbad twin, one being that of the axis of the prism zone, another perpendicular to it and the clinopinakoid—the orthodiagonal; and a third perpendicular to those two, the normal to the orthopinakoid, and to one of these the principal axis of the quartz must in such a case be parallel. But it is far more likely that there is no definite relationship between the axes of the two minerals, and that quartz may intergrow with felspar in any position. This conclusion is necessitated by the fact that in one felspar certain areas of quartz may extinguish in one position, others in another, and between these positions no evident connection may be made out. In felspar sections, which, as far as can be ascertained, are as nearly as possible in parallel directions, the extinction of these sets of quartz patches may vary widely from one another. Such could not be the case in a parallel growth after the law just explained, and as no other directions satisfy the necessary conditions, it seems proved that the relationship between the two minerals is an entirely arbitrary one, however much their intimate association and frequent intergrowth may predispose us to a contrary conclusion.

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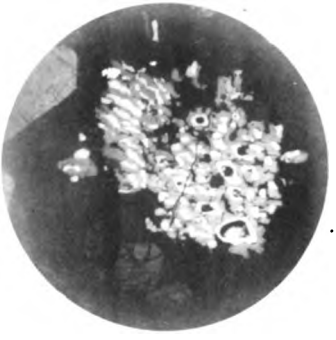

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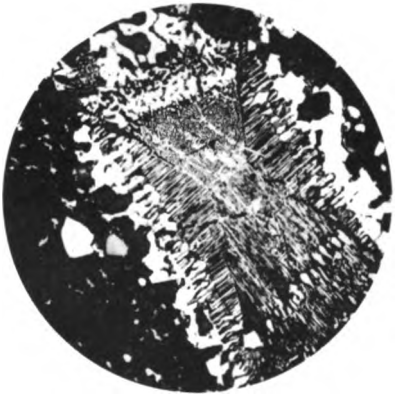

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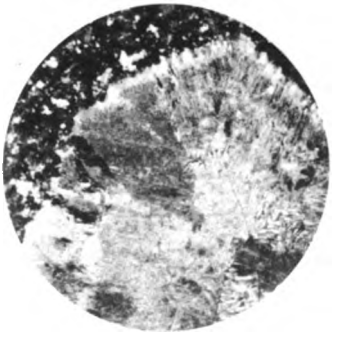

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Phenocrysts of micropegmatite occur also in the quartz-porphyry ("Felsophyre") of Nossen, Saxony, and, as will be seen from the photograph (plate xxvii., fig. 5), they show an almost complete resemblance to those of the Black Hill felsite. Here we have the same hour-glass structure resulting from the regular disposition of the quartz wedges in two systems, with their axes perpendicular to the four principal faces of the crystal. The micropegmatite is much coarser than in the Scottish rock. The outlines of the crystal are obviously those of felspar, though, owing to the absence of a felspar rim, the idiomorphism is not complete, the margin being largely composed of quartz grains of irregular shape and orientation. The formation of quartz has in this case outlasted that of felspar, without leaving any trace of the outlines of quartz in the aggregate. In polarised light the felspar as a whole has a uniform extinction, but this is only roughly true of the quartz, certain areas of which extinguish in a slightly different position from the remainder.

PLATE XXVII.

Fig. 1.—Corroded micropegmatite phenocryst from the Liparite of Hlinik, Hungary, magnified 15 diams.

Fig. 2.—Micropegmatite phenocryst from Black Hill, Pentlands, × 35 diams. The section passes traversely across the end of an hour-glass crystal. It consists of five areas, four of which are marginal, and in each the quartz lies in strings perpendicular to the face of the crystal. In the central area the quartz strings are cut obliquely, being perpendicular to a face not seen in section, and roughly parallel to the plane of the slice.

Fig. 3.— Do. magnified 35 diameters, a longitudinal section of an hour-glass crystal showing four marginal areas, and in the centre a small patch which is the hour-glass segment of one of the faces parallel to the plane of section, cut transversely.

Fig. 4.— Do. part of a large phenocryst, × 25 diameters. (From a section kindly given me by Mr Allan M. Douglas.)

Fig. 5.—From the Felsophyre of Nossen, Saxony. × 16 diameters.

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LIX.—*On the Occurrence of Carboniferous Limestone Fossils at Viewforth, near Largo, Fife.* By JAMES W. KIRKBY. (Plate XXVIII.)

(Read 21st April 1898.)

THE Fifeshire Coal-measures are traversed by a series of large east and west faults, which being all risers north, thrust the strata to the east step by step, until the last, and most northerly, cuts off the field in that direction where it runs into the sea at the Temple, at the far end of the village of Largo. This is evidently the largest fault of the set, for on the shore are seen the Red beds of the Coal-measures on the one side of the dislocation, and strata considered to belong to the Carboniferous Limestone Series on the other. It has always been difficult, however, to estimate the amount of throw of the fault on account of the absence of any known bed—such as a limestone, or of fossils (*Stigmaria* excepted) in the last mentioned rocks, from which some idea of their horizon might be obtained. As a possible help in this direction these remarks are offered, as they record the recent discovery of marine fossils in the strata in question.

These strata extend only a short distance—about 500 yards —along the shore and then end abruptly against the volcanic ash that commences at Viewforth and ranges by Johnston's Mill eastward. They mainly consist of thin light-coloured sandstones, shales, and fireclays, along with three or four coaly bands. Altogether there are nearly sixty feet of them. For the most part they lie rather flat, dipping gently inland in synclinal curves, except at the east and west ends, where they rise into small anticlines (now planed down) before dipping against the Temple fault in the one case, and into the ash on the other. When the shore has been well scoured by an easterly gale the section is a very instructive bit of geology. At other times when partly hidden by sand it is not so easily read.

The detailed succession of these beds is as follows:—

	Ft.	Ins.
1. Sandy shale with irregular sandstone bands, reddish above, grey below. Seen at high-water mark .	10	0
2. Yellow sandstone, thin-bedded and ripple-marked below. Fragments of plants . . .	5	0
3. Grey shale with flat ironstone nodules . .	5	0

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		Ft.	Ins.
4.	Grey shale and fireclay with bands of black shale and coal. *Stigmaria*	5	0
5.	Light fireclay with many sandy concretions	3	0
6.	Light sandy fireclay with two 3-inch bands of black shale and coal. Full of Stigmarian roots and rootlets	3	0
7.	An irregular bed of soft sandstone	1	6
8.	Light sandy fireclay. *Stigmaria*	4	0
9.	Light sandy shale, well stratified	2	6
10.	Dark grey shale	1	6
11.	Sandstone	6	0
12.	Sandstone and shale	6	0
13.	Grey shale	1	2
14.	Sandy bands and shale	2	0
15.	Sandy shale	1	0
16.	Calcareous shale with cement-stone nodules. Crinoids, *Productus*, *Aviculopecten*, and other marine fossils	1	6
17.	Shale	0	6
18.	Black shale with thin band of coal below. Fish-remains and stray marine shells	0	9
19.	Fireclay		

The lowest beds are only seen at the east anticline, where they crop out in an acutely-ovate way all round a flat crown of the fireclay No. 19. It is here where the fossiliferous shales are seen, and only here, for the roll of the strata at the west end of the section does not bring beds so low to the surface again. The accompanying horizontal section may assist in making this description clear.

The fossils occur chiefly in the shale and cement-stone nodules, No. 16: though some are found in the black shale, No. 18. They are not numerous—the Ostracoda excepted—and require some looking for. Few of the specimens that have been obtained are perfect; and most of them are small, and apparently of dwarfed growth. This is the case even with the Ostracoda, which, as well as being the most abundant, are the most characteristic species of this little fauna.

In No. 18, there occur the scales, teeth, and bones of small ganoid fish; some palatal teeth, and a few specimens of two species of mollusca:—*Leda attenuata* and *Lingula mytiloides*.

The following List includes all the species found:—

Mollusca.

Loxonema (?) sp.
Naticopsis sp.
Pleurotomaria sp.

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Mollusca—*continued.*
- Leda attenuata, Fleming.
- Aviculopecten sp.
- Pteronites sp.
- Athyris Royssii, Lév.
- Terebratula sp.
- Productus semireticulatus, Martin, var. Martini.
- Discina nitida, Phillips.
- Lingula mytiloides, Sowerby.

Polyzoa.
- Fenestella sp.
- Ceriopora similis, Phill.

Echinodermata.
- Archiocidaris sp.
- Crinoid stems.

Entomostraca.
- Cypridina Phillipsiana, Jones.
- Cytherella valida, Jones and Kirkby.
- —— —— var. affiliata.
- —— sp. nov.
- —— sp. nov. (?)
- Bairdia plebeia, Reuss.
- —— Kingii, Reuss.
- —— ampla (?) Reuss.
- —— subelongata, J. & K.
- —— nitida, J. & K.
- —— amputata, Kirby.
- —— siliquoides, J. & K.
- —— curta, M'Coy, var.
- —— legumen, J. & K.
- —— submucronata, J. & K.
- —— brevis, J. & K.
- —— Hisingeri (Münster).
- —— sp. nov.
- Bairdia (?) æqualis, D'Eichwald.
- Bythocypris thraso (?) J. & K.
- —— cuneola, J. & K.
- —— Phillipsiana, Jones & Holl, var. carbonica.
- —— (?) sp. nov.
- Darwinula Berniciana (?) Jones.
- Krithe subreniformis, J. & K.

Foraminifera.
- Endothyra Bowmani, Phillips.
- —— globularis, D'Eich.
- —— radialis, Brady.
- Lagena Parkeriana, Brady.

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The larger fossils (Mollusca, etc.), of this List are such as are known and as might be expected to occur in Carboniferous Limestone strata, but neither as a group nor individually do they mark any particular horizon in that division. In fact, several of them are found in the upper portion of the Calciferous Sandstone, and the species of *Lingula*, *Discina*, and *Productus* range up as high as the Coal-measures.

The Entomostraca are in the main Carboniferous Limestone species, though they—nearly all of them—are met with as low down in the Calciferous Sandstone as the "Encrinite Bed." Two of them, *Bairdia nitida* and *Krithe subreniformis*, have not hitherto been found out of Lower Carboniferous strata. *Bairdia* (*?*) *æqualis* was previously known only from Russia, and the species referred to, *Bairdia Kingii*, is a Permian form which has not been seen in Carboniferous strata before. Still the great number of *Bairdiæ* in the List seems to stamp the group as of Carboniferous Limestone age, for it is only in that formation that the members of this genus are ever really abundant as species and individuals.

Nevertheless there is something that is peculiar about these little fossils as a group. They are mostly of small growth, and they are a plain lot as to surface and other ornament, which is mainly due to the absence of species of *Leperditia*, *Beyrichia*, and *Kirkbya*, that are nearly always represented among the Ostracoda of the Carboniferous Limestone series. These features, along with presence of new forms, give the group a character different to any other that I have studied from Carboniferous strata, and so render it difficult to say as to what particular horizon it may be likely to belong.

It may be added that none of these Entomostraca have ever been found in the Coal-measures. The same may be said of the Foraminifera.

However, as tending towards fixing its horizon, it seems safe to say that it is neither the Levenseat nor the Gair Limestone, which are the two first calcareous beds below the Millstone Grit, both of which are well-marked and persistent limestones in Fife, as well as in other parts of Scotland. The former, in fact, is seen in its normal thickness about two miles to the north-west, at Tomsford, where it was formerly worked for lime burning, and the latter rather further away, in Kennoway Den, and on the coast at Pathhead. These are good limestones, with characteristic and well developed suites of fossils that have no resemblance to the Viewforth bed in any way.

The next well-known marine zone is the Index Limestone, which is thin and not often exposed in natural sections, though sometimes passed through in sinking and boring to the lower

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coals in Fife. It is less constant in character than the Levenseat and Gair Limestones, and its fossils are not so well known. So far as I have had the opportunities of examining the Ostracoda, they differ from those of Viewforth, owing to the prevailing species belonging to such types as *Beyrichia*, *Ulrichia*, and *Kirkbya*, instead of to *Bairdia* and *Cytherella*.

But it has been pointed out to me by Mr B. N. Peach that the Index Limestone, besides being everywhere thin and inconspicuous in Fife, is usually associated with volcanic ash; and that recent evidence from bores shows that the adjacent interstratified ash and agglomerate on the flanks of Largo Law are somewhere about its position. Hence it is probable that the peculiarities observable in the Viewforth fossils, including the dwarfing of the Mollusca and Ostracoda, are due to the unfavourable physical conditions that prevailed about this period of Carboniferous time in the Fife area, and more especially in this—the Largo Law—portion of it. So that it seems likely that the shale containing the fossils, if not the exact equivalent of the Index Limestone, is a local marine bed that comes in somewhere near that horizon.

I see nothing to add to this, and therefore adopt Mr Peach's views, more especially as to it possibly being a local marine horizon near the Index Limestone rather than exactly representative of it; for the next known marine zone is below the lower coal series, and about 1000 feet beneath the Index Limestone, which seems to be too far down for the Viewforth strata, when there is no evidence of the presence of the lower coals in the district between Viewforth and the Levenseat Limestone at Tomsford.

The approximate position of the strata on the south or dip side of the Temple fault is rather more easily arrived at, for the upper red beds of the Coal-measures ($d^{5'}$ of the Geol. Surv.) come on in regular order a little west of Largo Harbour, following the same easterly dip as the workable coal portion of the same series (d^5 of the Geol. Surv.) that is exposed for a thickness of 170 feet on the east side of the fault and ash neck at Drummochie. For about 1100 yards along the shore these upper red beds are seen more or less clearly; at first with a fairly steep dip, and afterwards, in front of Lower Largo village, with an easier inclination; though the whole section is never sufficiently uncovered to make exact measurement possible. Partly by actual measurements, and partly by estimated dip, their thickness has been made out to be fully 500 feet. This, added to the lower or workable coal portion of the Coal-measures, the Millstone Grit, and the Carboniferous Limestone

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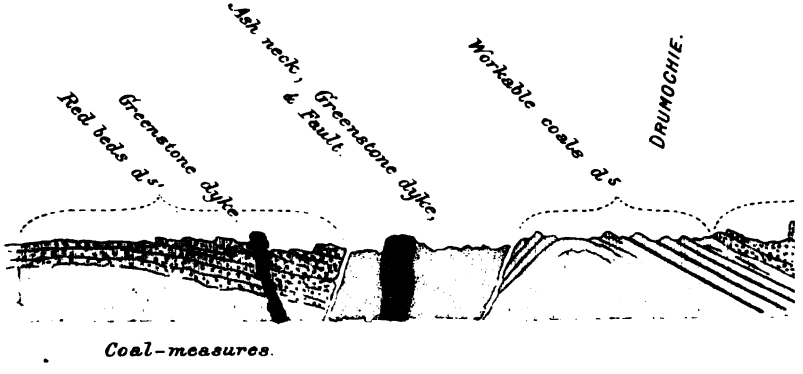

SKETCH SECTION OF CARBI

Jas W. Kirkby. del.

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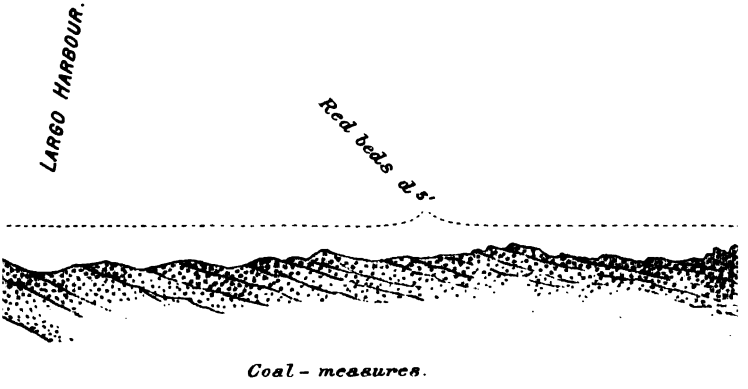

IIFEROUS ROCKS ON COAST OF FIFE FROM WEST OF

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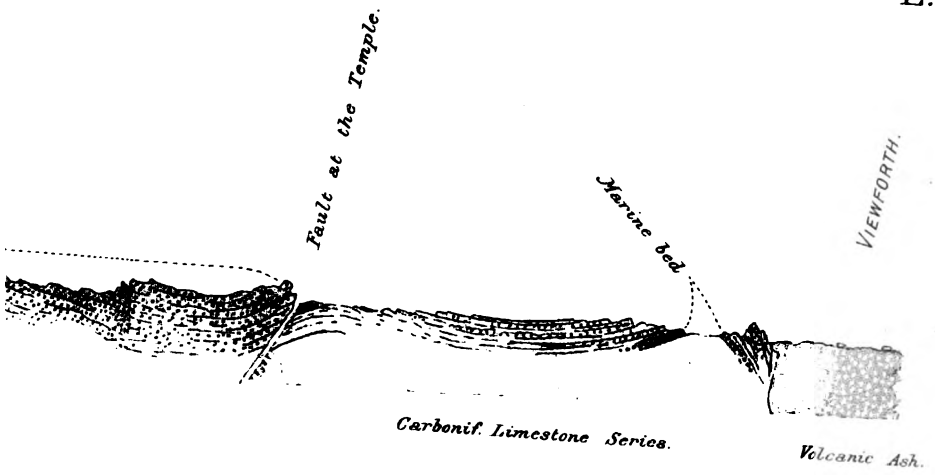

OM WEST OF DRUMOCHIE TO VIEWFORTH.

M'Farlane & Erskine, Lith Edin.

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series down to the Index Limestone, brings the throw of the fault out as follows:—

		Feet.
Coal-measures	Red beds	500
	Workable coals	600
Millstone Grit		300
Carboniferous Limestone Series to the Index Limestone		1000
		2400

This amount of throw is obtained on the assumption that the lower portion of the Coal-measures and the Millstone Grit are less developed in this region than further to the west. There is good evidence that the former is less than half as thick from the base of the Red beds down to the Chemise coal, at Drummochie, to what it is at Wemyss. But for the measures below the Chemise coal, and for the Grit, it can only be said that I think they probably follow the same process of thinning out. Had the maximum thickness of these Upper Carboniferous strata been taken as seen about Wemyss and Dysart, and as given in the "Vertical Sections Illustrative of the Coal Fields of Fife," by J. S. Grant Wilson, the drop on the west side of the Temple fault would have come out as about 4400 feet.

The Foraminifera in the preceding List of Fossils were determined by Professor T. Rupert Jones,—who also assisted in the determination of the Entomostraca.

Note.—Since the reading of this paper, marine shells (*Productus*, sp.) have been found in a shale that outcrops on the east side of the little den that runs up by the Serpentine Walk, Largo. This locality is about 600 yards north-west of the fossiliferous beds at Viewforth, and in the same series of strata, though evidently rather higher in position. The shale is red and only a thin band, and has a sandstone (also red) overlying it.

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LX.—*Note on the Feldspars of Canisp.*

By JAMES CURRIE, M.A., F.R.S.E.

(Read 21st April 1898.)

EVERY visitor to Loch Inver in Sutherland is familiar with the red porphyry of Canisp. Ice-borne blocks are to be seen all along the shore of the loch, in the bed of the Canisp Burn, and built into nearly every wall, where their bright red colour and large embedded crystals must attract the attention of the least observant. These crystals have been very fully described by Professor Heddle; and it is with some diffidence that I communicate this note of a single short day's gleaning in a field where he has harvested.

The two feldspars present in this rock are Orthoclase, and a plagioclase that may fairly be classed as Albite, although it contains a small proportion of lime. Owing probably to the presence of this constituent, the Albite weathers with markedly greater ease than the accompanying Orthoclase. With still greater ease the paste in which the feldspars are embedded decomposes into a red clay, from which the crystals can readily be extracted.

The Orthoclase of Canisp occurs in distinct and well developed crystals up to about 20 mm. in length. The predominant forms are *b*, *c*, *m*, with *o* and *y* always present, but always subordinate. Dr Heddle says that the form *z*, truncating the edge *b*/*m*, occurs only occasionally. It is often difficult, because of the rounding of the edges of the crystals, to determine with certainty the presence of narrow faces such as these, but this form seems to be shown by about 20 per cent. of the crystals that I gathered from immediately below the summit. The only other form mentioned by Dr Heddle is *g*. This I did not observe on any of my specimens; but many of these seemed to show, more or less obscurely, a truncation of the edge *b*/*c* by the form *n*. About 15 per cent. of the crystals from the summit were interpenetration twins, so that there at least these cannot be said to occur "somewhat rarely." They are generally of the ordinary Carlsbad type, with the twin-plane *a*; but in one instance the crystal was twinned on *m* (110). Examples of this rare law have hitherto, so far as I know, been reported only from the Riesengebirge, the Fichtelgebirge,

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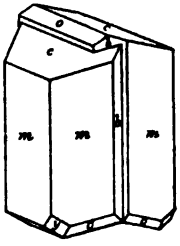
and Cornwall: it is, at any rate, exceedingly rare. The annexed figure will serve to show the manner in which the individuals are united. I am indebted to Professor Hintze of Breslau for the recognition of the law of twinning in this case.



There are considerable variations in the relative frequency of the two feldspars, and as a rule the Albite crystals are not nearly so numerous as those of Orthoclase. Low down on the north-west slopes, however, I picked up one small and much decomposed block about 20 cm. in diameter, from which the feldspar crystals could be extracted with little difficulty. This block yielded Albite only. Although in such close proximity to one another, the crystals varied among themselves both in the forms present and in habit. They also differed to some extent from those already described by Professor Heddle.

In the first place, apparently simple crystals were not uncommon. These showed the combinations *bcmMy. . . f . . z . . fz.* Neither *f* nor *z* occurred on Dr Heddle's single simple crystal, which however bore three other faces not observable on any of my specimens. Some of these were squat and thick, but the majority were thin tabular parallel to *b*.

Out of a score of crystals obtained from the little boulder, two were interpenetration-twins corresponding to Carlsbad twins, the combinations being *bcmMy* and *bcmMyfz*.[1] The latter specimen is unusually large for this locality, being over 2 cm. in length. Many other specimens show contact-twinning according to the same law.

Where the Orthoclase is penetrated by Albite crystals, as it not rarely is, the similar orientation of the two crystals is well seen. The brachypinacoids of the two crystals are parallel, as are the edges *m*/*m* of the Orthoclase with *m*/*M* of the Albite. The basal planes are either parallel or inclined at an angle of about 53°, as if the two crystals were twinned according to the Carlsbad law.

The same intimate relation between the two minerals is even more strikingly shown by the manner in which the Albite is sometimes intergrown with the Orthoclase. It thus occasionally forms not only a mere sheath as described by Professor Heddle, but an integral part of a compound crystal, portions of the Orthoclase crystal—irregular in outline, but bounded by planes parallel to the faces (actual or possible) of the latter—being

[1] The lettering employed here to denote the crystal faces of the two feldspars is that used by Dana in the 6th Edition (1892) of his System of Mineralogy.

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absent, and these parallelopiped or wedge-shaped portions being occupied by Albite.

This substitution of Albite substance for Orthoclase seems to me to be not perhaps a proof but a strong indication of the crystallographic similarity of the Potash and Soda Feldspars, and so far as it goes it supports the views of Mallard, Groth, Brögger, and Hintze, as to the essential identity of so-called "Ortho"-clase with Microcline.

So far as regards the order in which the two minerals were formed, it would hardly seem to have been (as Dr Heddle appears to indicate) first the Orthoclase and then the Albite: but rather, first Orthoclase alone, then Orthoclase and Albite, and finally Albite alone.

That it has been possible to add anything at all—however minute in this case the contribution may be—to the mineralogy of a district specially studied by Professor Heddle is a further proof, if such were needed, that in no case should the mineralogy or geology of any part of the country be considered as exhausted. A careful search will often reveal, even to the comparatively inexperienced, points of interest which have escaped the notice of the most illustrious predecessors.

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